

Multiple Uses of the Coastal Zone In
a Changing World. Jun 25-26, 1992

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NRC Retreat

"Multiple Uses of the Coastal Zone in a Changing World"
June 25-26, 1992

National Academy of Sciences
J. Erik Jonsson Woods Hole Study Center

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NATIONAL RESEARCH COUNCIL
COMMISSION ON GEOSCIENCES, ENVIRONMENT, AND RESOURCES

2101 Constitution Avenue Washington, D.C. 20418

EXECUTIVE OFFICE

202/334-3600

"Multiple Uses of the Coastal Zone in a Changing World"
June 25-26, 1992

AGENDA

National Academy of Sciences
J. Erik Jonsson Woods Hole Study Center
Carriage House
314 Quissett Avenue
Woods Hole, Massachusetts
(508) 548-3760

Wednesday, June 24, 1992

8:00 -9:00 p.m. Meeting of steering committee and available paper presenters at Study Center, Sunporch

Thursday, June 25, 1992

7:00 a.m. Transportation from hotel to Study Center

7:15 a.m. Breakfast at Study Center

8:00 a.m. Welcome and Goals -- M. Gordon Wolman (CGER Chair) and Karl K. Turekian (Retreat Chair)

8:15 a.m. A Synopsis of "Coastal Meteorology: A Review of the State of the Science" -- Richard Rotunno (National Center for Atmospheric Research)

9:15 a.m. Modeling Transport Processes in the Coastal Ocean -- Alan Blumberg (Hydroqual, Inc.) ✓

10:15 a.m. Break

10:30 a.m. Coastal Geomorphology -- Stephen Leatherman (University of Maryland)

11:30 a.m. Rivers and Estuaries - A Hudson Perspective -- Richard Bopp (Rensselaer Polytechnic Institute) ✓

12:30 p.m. LUNCH

1:30 p.m. Types of Coastal Zones: Similarities and Differences -- Douglas Inman (Scripps Institute of Oceanography)

1:55 p.m. Instructions to breakout groups and adjourn to rooms 202 and 309

2:00 p.m. Discussion of topics in breakout groups

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4:30 p.m.	Return to plenary meeting for discussion summaries - reports by facilitators
5:15 p.m.	Recess
6:00 p.m.	New England Clambake at Study Center
8:00 p.m.	Adjourn for day and transportation to hotel

Friday, June 26, 1992

7:00 a.m.	Transportation to Study Center
7:15 a.m.	Breakfast at Study Center
8:00 a.m.	Coastal Wetlands: Multiple Management Problems in Southern California -- Joy Zedler (San Diego State University)
9:00 a.m.	Landscapes Use and the Coastal Zone -- Eugene Turner (Louisiana State University)
10:00 a.m.	Break
10:15 a.m.	Coastal Pollution and Waste Management -- Jerry Schubel (State University of New York at Stony Brook)
11:00 a.m.	Coastal Management and Policy -- William Eichbaum (The World Wildlife Fund)
12:15 p.m.	LUNCH
1:00 p.m.	Conflicts in Coastal Zone Use -- Edward Goldberg (Scripps Institution of Oceanography)
1:30 p.m.	Discussion of topics in breakout groups in rooms 202 and 309
4:30 p.m.	Discussion summaries in plenary meeting
5:00 p.m.	Summary remarks
5:30 p.m.	Adjourn retreat and transportation to hotel

Saturday, June 27, 1992

7:45 a.m.	Breakfast at Study Center
8:30 - 10:00 a.m.	Working meeting of steering committee at Study Center

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June 25-26, 1992
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A Synopsis of "Coastal Meteorology: A Review of the State of the Science "

Richard Rotunno, NCAR

Introduction

According to a recent study by the Department of Commerce, almost half the U.S. population lives in coastal areas and so are affected by the unique weather and climate of the coastal zone. Under the auspices of The National Academy of Science, the Panel on Coastal Meteorology has just completed a study of the state of the science of coastal meteorology. This presentation will cover the highlights of the study by concentrating on the perceived major scientific problems, and opportunities for progress.

Coastal meteorology is the study of meteorological phenomena in the coastal zone caused, or significantly affected, by the sharp changes that occur between land and sea in surface transfer and/or elevation. The coastal zone is subjectively defined as extending approximately 100 km to either side of the coastline. Examples of coastal meteorological phenomena include the sea breeze, sea-breeze-related thunderstorms, coastal fronts, marine stratus, fog and haze, enhanced winter snow storms and strong winds associated with coastal orography. Increased knowledge of several or all of these is important for studies in the physical and chemical oceanography of the coastal ocean. The practical application of this knowledge is vital for more accurate prediction of the coastal weather and sea state which affect defense, transportation and commerce, and pollutant dispersal.

The dynamical meteorology of the coastal zone may be thought of in terms of three subsidiary ideal problems; these three problems formed the organizational basis of our study. The first problem is one where the coastal atmospheric circulation is primarily driven by the contrast in heating, and modulated by the contrast in surface friction, between land and sea. The second problem is one where the primary influence is due to the steep coastal mountains whose presence may induce strong along-shore winds, and other complex flow patterns. The third class of phenomena broadly consists of larger-scale meteorological systems that, by virtue of their passage across the coast-

line, produce distinct smaller-scale systems. Of course, complex reality is always some combination of these idealized problems.

The Atmospheric Boundary Layer

The transfer of heat, momentum, and water vapor between the atmosphere and the lower surface (be it land or sea) is basic to these three ideal problems. As such, our study begins with an assessment of, and prospects for improvement in, our understanding of the approximately 1km-deep layer of air adjacent to the surface called the atmospheric boundary layer (ABL.) Study of the ABL is intended to reveal how the effects of surface transfers are distributed upward. The best understood model of the ABL is when it is the cloud-free and convective and horizontally homogeneous. However, near the coast, the ABL is anything but. Stratus, fog and drizzle complicate the situation as they depend on a complex interplay between cloud physics, radiation and turbulence. Perhaps the most severe scientific problem is how to treat boundary layers that are not horizontally homogeneous. Over land, there is still significant uncertainty on the nature of surface transfer from terrain with variation in vegetation and usage such as occurs along the coast. Over the ocean, those surface transfers are determined by the sea state, which in turn, is determined by the atmospheric flow, which is influenced by the surface transfers, etc. This fundamental coupling has been long-recognized, however there is another order of complexity over the coastal ocean because there the sea state is significantly influenced by the ocean shelf.

Areas in need of research are:

- ABL processes in inhomogeneous and nonequilibrium conditions. A better understanding of these may lead to better surface-flux and mixed-layer scaling theories.
- Fundamental relationships between the ocean wave spectrum, the surface fluxes, and bulk ABL properties.
- Coastal marine stratocumulus.

Thermally Driven Effects

Although the recognition of the land-sea breeze dates back to antiquity, the deeper understanding needed to make accurate forecasts is still lacking. The land-sea breeze

is produced by virtue of the generally different temperatures of the land and sea which produce an across-coast, air-temperature (density) difference. After this circulation begins, however, it modifies the conditions that produced it; thus the difficulty in making precise predictions lies with the difficulty in understanding more precisely the nature of this feedback. The aforementioned uncertainties in our understanding of the ABL are certainly central problems here. Beyond the simple two-dimensional picture, coastline curvature, near-shore islands, different synoptic-scale wind orientation present important scientific problems. Perhaps the most challenging problem is the interaction of the land-sea breeze with cumulus convection. Issues associated with two special types of thermally driven phenomena (coastal fronts and ice-edge boundaries) are also discussed in the study.

Areas identified for further study are:

- Observational and modeling studies of the land-sea breeze to cover the entire diurnal cycle, with emphasis on improving knowledge of offshore regions.
- The fine-scale structure of the sea-breeze front, including the associated vertical motions, and internal boundary layers above complex coastlines and heterogeneous surfaces.
- Three-dimensional interactions of the land-sea breeze with variable synoptic-scale flow, nonuniform land and water surfaces, irregular coastlines and complex terrain.
- Dynamical interactions of the land-sea breeze with stratus clouds, and with precipitating and nonprecipitating cumulus convection.
- Geographical distribution, spatial coverage, and modes of propagation of coastal fronts.
- Processes of heat and moisture flux from leads and polynyas.

The Influence of Orography

Coastal mountain ranges can significantly affect coastal meteorology. In many situations the coastal mountains act as a barrier to the stably stratified marine air; thus air with a component of motion toward the barrier at great distance must eventually turn and flow along the barrier. Also the coastal mountains may act like the side of a

basin within which the marine air is contained; under the influence of the earth's rotation, waves known as 'Kelvin waves', may propagate along the basin-wall-like coastal mountain. Special boundary-layer flows are also observed under the influence of the coastal mountains. For example, during the Coastal Ocean Dynamics Experiment, a strong along-shore jet was documented. It had a strong diurnal component as evidenced by the depression on the marine inversion near the coastal mountains during the day. The boundary layer structure showed interesting complexity inasmuch as the potential temperature was well-mixed to the inversion but the wind speed increased strongly through the same layer. Phenomenon that appear similar to flow separation in classical fluid dynamics also occur in the lee of capes and other coastline salients. These types of motion are important components of the meteorological problem in these coastal regions.

Areas identified for further study are:

- Case studies of structure and path of storm systems modified by coastal orography.
- Climatology of synoptic regimes conducive to coastally trapped phenomena.
- Methods to include coastal phenomena in numerical forecast models.

Interactions with Larger-Scale Systems

As larger-scale meteorological systems move across the coast, they are affected by some combination of the effects discussed in the previous two paragraphs; in some situations, distinct subsystems, which would not exist without the coastal influence, are produced. Examples of these effects include cyclogenesis enhanced at the east coast of the U.S. as upper-level disturbances cross the Appalachians and encounter the strong baroclinic zone at the coast, flow along the coast in winter with strong cooling of the air on the landward side leading to the formation of fronts, and land-falling hurricanes whose low-level flows are so modified as to favor the formation of tornadoes.

Areas identified for further study are:

- Dynamics of the local intensification of cyclone winds by coastal topography, and the resulting modification of storm intensity and motion.

- The cause of tornadoes associated with land-falling hurricanes.
- The influence of the coastal heating discontinuity in the along-shore propagation and local intensification of coastal fronts.
- The influence of coastal fronts on midlatitude coastal cyclogenesis.

Influences on the Coast Ocean

In general, the ocean affects, and is affected by, the atmosphere. We discuss next aspects of this interaction particularly important for the coastal zone (shelf waters). In the northern hemisphere, an along-coast wind with the coast on the left brings the sea into motion in the along coast direction, due to the Coriolis effect the water motion is deflected away from the coast necessitating its replacement by water from below—this phenomenon is known as coastal upwelling. The water from below is colder, and in general is of different chemical and biological composition. The details of the cross-shelf transport (necessary to feed the upwelling) are poorly understood, since the ocean is responding to atmospheric influences over a large range of time and space scales. This wind-stress data from the Coastal Ocean Dynamics Experiment (CODE) shows the mean and a considerable standard deviation. Also the along-shore ocean currents may be highly irregular. There is evidence the some of the irregularity is due to wind-stress variations along and across the coastal zone.

Also the colder water along the coast now means there is yet another across-coast temperature difference that can produce changes in the atmospheric circulation, which can affect the ocean, etc. Interactions of this nature are important to the understanding of the coastal ocean, and the chemical and biological processes occurring there.

Areas identified for further study are:

- The coupled ocean-atmosphere processes that control the interactions between the wind field, ABL structure, and upper ocean.
- The local physical and chemical processes governing air-sea fluxes of momentum, heat, moisture, particulate and gas within an inhomogeneous coastal ABL and variable wave state.
- The role of remote mesoscale spatial inhomogeneities in controlling atmosphere-

ocean dynamics in a coastal environment.

Air Quality

Another important application of coastal meteorology is to the prediction of pollutant dispersal. Our study covered issues relevant to the coastal environment. The highly variable winds near the coast may sweep pollutants out to sea on a land breeze, but then bring them back with the sea breeze. More accurate estimates of the vertical motion fields associated with these wind systems are critical for determining the layers at which the pollutant will ultimately reside (and the horizontal direction in which it will move.)

Further progress here would be helped by:

- Comprehensive tracer studies conducted at increasingly more complicated coastal sites. This would allow for evaluation, validation, and eventual widespread use of improved dispersion models.
- Improved coordination between air pollution and boundary layer field observation programs conducted on both sides of the littoral.

Capabilities and Opportunities

Observations

The present in observational network of routine in situ data is not adequate for most applications. The coastal rawinsondes, especially over the west coast, are very sparse. The buoy network is sparse and only measures conditions near the surface. There are transient ship reports that supplement the buoy reports.

As part of NOAA's observational equipment modernization will offer some improvements and some degradation. NEXRAD will provide an increase in over-water coverage: Doppler winds out to 150km, reflectivity out to 400 km. Returns from the moving sea surface may possibly be interpreted to get surface winds. No new rawinsondes are planned, and some coastal sondes may be moved inland. Efforts continue to use passive and active satellite techniques to infer the atmospheric and sea state. Surface based remote sensors can give highly detailed spatial and temporal detail in the boundary layer.

Models

The emergence of high performance workstations having substantial fractions of the calculation speed performance and superior throughput of present day mainframe supercomputers will allow researchers to run regional models with high resolution and to conduct numerous sensitivity studies.

Human Resources

It is the experience of the panel members that few universities have courses in the meteorology of coastal zones. Related areas of meteorological instrumentation and observational techniques are also under-represented.

To improve our capabilities and opportunities the Panel recommends:

- The use of recently developed remote sensors to obtain detailed four-dimensional data sets to describe coastal regions and the upgrade of buoy and surface station networks to obtain quality, long-duration data sets.

- The on-site use of affordable, high-performance work stations that can provide decentralized computations during study of local phenomena, be used to determine the sensitivity of coastal processes to various influences, and be used to study techniques for assimilating data into real-time forecasts.

- The increased use of conferences, short courses, and university training programs to encourage more scientists to explore the meteorology of the coastal zone.

MODELING TRANSPORT PROCESSES
IN THE COASTAL OCEAN

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1. INTRODUCTION

As population growth and industrial development continue along the coastal zones, near-shore waters over the continental shelf are being subjected to increasing environmental stresses from numerous sources. Discharges of municipal and industrial wastes, agricultural runoff, combined sewer overflows and waste spills of potentially toxic substances from coastal commerce contribute collectively to a host of water quality problems. The eventual impact of these discharges is the result of complex interactions among the pollutant inputs from all sources, the various chemical forms of the constituents present in the water column and their associated chemical reactions with each other and the complex marine food chains which can exchange nutrients and other chemicals between the water column and the underlying sediment. A common element to the understanding of these interactions is the need to define the hydrodynamic transport processes governing the movement and mixing of the constituents as forced by various hydrographical (runoff, estuarine circulation), meteorological (surface wind, heat fluxes), open ocean (large scale ocean circulation), astronomical (tides) and internal (density gradients) forcing mechanisms.

The circulation occurring over the continental shelf typically exhibits considerable temporal and spatial variability. It is characterized by relatively, large-scale alongshore current systems which have a variety of interannual, seasonal and daily variations. The variability in circulation from place to place is evident in satellite sea surface temperature images which show patchy upwelling zones, filaments of cold water extending offshore, rotating eddies and other large-scale circulation features. Processes responsible for the circulation are wind driven currents and mixing which are often the dominant processes over the shelf, buoyancy effects which lead to plume and frontal formations, shelf-open ocean interactions where meandering offshore currents and mesoscale eddies can entrain much water from the shelf and tidal resonances which can produce large tidal currents and intense levels of vertical mixing.

Observational programs have been the cornerstone of our conceptual and theoretical understanding of currents and water properties in coastal regions. Our knowledge has increased because of the introduction of moored, hydrographic, Lagrangian and satellite based observations. However, to permit a consistent view of the circulation, each of these types of observations is needed simultaneously. Consider, for example, that in many coastal regions, the length scales of the hydrodynamical processes are characterized by an internal deformation radius (Rossby radius) of 5 to 15 km and by topographic variations ranging from 1 to 10 km.

Motions and water properties measured at stations separated by distances much greater than these length scales will, in general, tend to be only loosely related to one another. The sampling networks of hydrographic surveys and current meter moorings must be chosen within the Rossby radius. For coastal domains of small extent this is possible; however, for large regions it is not always feasible. There are also a host of issues associated with obtaining observations with the proper time scales. Satellites provide excellent spatial views that are, unfortunately, only "snapshots" in time. Current meters are better at addressing temporal variability since they employ sampling frequencies that are typically 30 minutes or less; however, their spatial coverage is limited. It is apparent, then, that observational programs can rarely be sufficiently dense in either space or time to provide an adequate description of the water mass and velocity fields of an evolving three-dimensional piece of coastal ocean. In recent years, coastal ocean circulation models have come to be depended upon, when properly tested and verified, to synthesize information from measurements and to provide a framework for investigating the basic processes of a region. As such, coastal ocean models play a critical role in determining how nutrients, sediment, contaminants and other water-borne materials are transported.

The purpose of this paper is to provide an overview of the processes governing the transport of water, dissolved substances and particles in the context of the design and development of a three-dimensional circulation model of Massachusetts Bay. The bay is ideally suited for the purposes of this paper because its circulation is a complicated function of winds, tides and river inflows, and because its environmental problems, caused by the introduction of wastes over many years, are typical of those found off many large metropolitan areas. Before the presentation of the Massachusetts Bay case study, a short discussion of numerical models themselves will be provided, briefly reviewing where coastal ocean circulation modeling is today and describing the physically, comprehensive circulation model developed by Blumberg and Mellor (1980) which will be used to elucidate the various transport processes in Massachusetts Bay. In the final section, some thoughts on the important issues of coastal ocean modelling that need to be addressed in the future will be put forth.

2. COASTAL CIRCULATION MODELING

Significant progress has been made in the development of limited-area coastal circulation models. The state-of-the-science has progressed to the point where programs to develop and validate a predictive system for the U.S. coastal ocean (Coastal Ocean Prediction Systems, 1990) are being proposed. There are now models being used routinely in the Great Lakes to determine water levels, currents and temperatures for periods going back to 30 years (Bedford and Schwab, 1990). Much of the increase in modeling activities is due to the availability of low cost, supercomputer resources and to the continued development of reliable numerical codes. Too many models exist to provide a comprehensive survey, here. The interested reader is referred to the monographs by Heaps (1986) and Nihoul and Jamart (1987) and to the review articles by Wang, et al (1990) and Blumberg and Oey (1985) for details concerning the status of coastal ocean circulation modeling.

The coastal ocean circulation model developed by Blumberg and Mellor (1980) called ECOM3D will be used as a framework for discussing the transport processes which operate in the coastal ocean. The model is three-dimensional and time dependent so that it can reproduce the complex oceanographic physics present over the shelf. Evolving water masses, baroclinic plumes, fronts and eddies are accounted for by prognostic equations for the thermodynamic quantities, temperature and salinity. Free surface elevation is also calculated prognostically so that tides and storm surge events can be simulated. Through these prognostic equations and the use of the full nonlinear form of the momentum equations, the processes relevant to a spectrum of nonlinear, stratified flows can be properly modeled. Coastal upwelling dynamics and the processes leading to stratified tidal rectification will be part of the simulated distributions. The vertical turbulent mixing processes are parameterized using the turbulent closure submodel of Mellor and Yamada (1982). This submodel contains non-dimensional empirical constants that are fixed by reference to laboratory data and are independent of particular hydrodynamic model applications. ECOM3D also incorporates a σ -coordinate system such that the number of grid points in the vertical is independent of depth so that the dynamically important surface and bottom boundary layers across an entire sloping shelf can be adequately resolved. The last model feature to note is the use of a curvilinear coordinate system, greatly increasing model efficiency in treating irregularly shaped coastlines and in meeting requirements for high resolution in specific local regions. A complete description of the governing equations and numerical techniques can be found in Blumberg and Mellor (1987). The model has been used in over 30 studies which have appeared in the

referred literature and is being exercised in an operational forecasting mode for the Great Lakes and in Norwegian coastal waters.

3. A CASE STUDY: MASSACHUSETTS BAY

Massachusetts Bay and Cape Cod Bay combine to form a roughly 100x50 km semi-enclosed basin with an average depth of 35 m located in the western Gulf of Maine (Figure 1). As in many coastal regions near major urban areas, the bays are used for a variety of purposes: commercial and recreational fishing, shipping, recreational boating, swimming, and as a repository for sewage effluent and dredged sediments. Currently, there is considerable controversy concerning the extension of the Boston sewage outfall pipe from the mouth of Boston Harbor to a site 9 miles offshore. The public living around the coast of Massachusetts and Cape Cod Bays is concerned that Boston is improving its pollution problem at the expense of the bays, and that swimming beaches, shellfish beds, fishing resources, and the endangered right whale population that feed in the bays may be jeopardized. To address these concerns ECOM3D is being used in conjunction with available observations to determine the fate and transport of contaminants, nutrients, and other water-borne materials in the bay, including effluent from the proposed outfall site. The region covered by the model encompasses all of Massachusetts and Cape Cod Bays as well as Stellwagen Bank (Figure 2). It includes the Merrimack River and extends offshore to a depth of about 200 m. The resolution of the curvilinear grid system ranges from a minimum of 600 m near the proposed outfall site to a maximum of 6000 m near the open ocean boundary. Vertical resolution is accomplished by using 10 σ -levels in the water column. Data for model calibration and verification was obtained during an intensive field program over the period 1990-1991 (Geyer et al, 1992).

3.1 Tidal Currents

The most predictable and often the strongest currents in the bays are produced by the barotropic tides, which have an average range of 2.6 m. Tides are introduced into the model by forcing the open offshore boundaries with sea surface elevation data from a well-calibrated, lower resolution Gulf of Maine model (Naimie and Lynch, 1991). Comparison of modeled currents with moored current observations from the winter (when the best analysis of the pure tidal signal can be made) reveals that both tidal excursions and orientations of tidal ellipses are reproduced well (Figure 3). Tidal excursions range from more than 12 km off Provincetown and in Boston Harbor, to less than 2 km in the deep central Massachusetts Bay. The tidal excursion at the proposed outfall is 2 km.

While the moored observations of tidal currents give some indication of the spatial variation verified at the moorings, can fill in the spatial structure, indicating regions of strong tidal gradients ... tidal mixing fronts may form as well as indicating features unresolved by the observations (Figure 4). The locations of the strong gradients on Stellwagen Bank and west of Provincetown are near regions frequented by the endangered North Atlantic right whales (Hamilton and Mayo, 1988). Therefore, resolution of the flow in these regions may be important in the determination of the effects of pollution introduced into the bays on the whale population.

Because of their strength, tides play an important role in vertical mixing processes, but since they are periodic at 12.4 hours (the M_2 constituent dominates here), they essentially displace material back and forth over the length of the tidal excursion with little net transport. The exceptions are when tidal currents act in conjunction with the bottom topography and coastline geometry to produce strong asymmetry between ebb and flood. The tides have a large effect on the flushing of Boston Harbor (Signell and Butman, 1992), and may be important locally at the tip of Cape Cod and along the western side of Stellwagen Bank, but play little role in transporting material over distances comparable to the size of the bays.

3.2 Subtidal Currents

Observations suggest that horizontal transport of material is accomplished by advection due to the mean flow through the bays and the dispersive effect of sub-tidal wind-driven and river runoff events. The mean flow generally supports the historical conceptual picture of a counterclockwise circulation (Bigelow, 1927; Bumpus and Lauzier, 1965; Brooks, 1985), made up of southwesterly inflow south of Cape Ann, southerly flow along the coast east of Scituate, and northeasterly outflow north of Race Point (Figure 5). This mean circulation pattern, however, is often altered by wind and runoff events, and except at the deep stations near Cape Ann and Race Point, the fluctuations are typically stronger than the mean. The proposed outfall site, in fact, is in a region of weak mean flow, apparently west of the stronger residual current system. This means that material here is mixed and transported by random fluctuations of wind and runoff events rather than being swept away by a persistent current. Using process-oriented modeling that examines the bays response to specified forcing conditions, the factors that are important for driving the mean flow and the low-frequency fluctuations can be determined.

3.2.1 Mean Flow

What drives the observed counterclockwise flow through the bays? One hypothesis is that it is simply an extension of the coastal current that exists in the Gulf of Maine (Bigelow, 1927; Bumpus and Lauzier, 1965; Vermersch et al, 1979). To test this hypothesis, the model is forced with a 3 cm offshore sea surface slope from the coast to the 100 m isobath along the northern boundary. This slope produces a 10 cm/s coastal current north of Cape Ann that is comparable to observed coastal current speeds (e.g. Vermersch, 1979). The simulation reveals that much of the Gulf of Maine coastal current moves southward following the bathymetry along the eastern flank of Stellwagen Bank, largely bypassing the bays (Figure 6). The coastal current explains the observed mean flow southeast of Cape Ann and at Stellwagen Bank (stations U2, U3 and U6 in Figure 5), but the counterclockwise flow that the coastal current drives in the bays is much weaker than observed. Adding the mean wind stress of 1 dyne/cm² to the coastal current forcing dramatically changes in the simulation of the mean flow. The mean wind is from the west, and drives a very realistic looking southeastward current along the coast from Boston to Cape Cod which exits the bays at Race Point (Figure 7). Thus remote forcing from the Gulf of Maine coastal current and the mean wind stress both play important roles in explaining the mean circulation in the bays.

3.2.2 Low-Frequency Fluctuations

The wind direction is one factor that strongly determines the response of the bays: northwest or southeast winds are aligned with the long-axis of the bays, and are therefore more efficient at driving circulation than southwest or northeast winds (Geyer et al, 1992). When the waters of the bays are unstratified, as in winter, northwest winds drive strong flow downwind at the coast, which piles up water in Cape Cod Bay, creating an along-bay pressure gradient (Figure 8). This pressure gradient drives return flow against the wind at depth (Figure 9). When the wind blows from the southwest during well-mixed conditions, the currents are substantially weaker (Figure 10).

Another factor that has a major impact on the wind response is the degree of stratification. Results from two years of measurements near the proposed outfall show that the surface current fluctuations are strongest in summer, when the wind stress fluctuations are weakest (Figure 11). One hypothesis is that the wind stress is more efficient at driving surface currents in summer, when strong stratification reduces the frictional

resistance of the surface layer. Modeling the response of the bays to southwest wind conditions (Figure 12) reveals a much different picture than the unstratified case (Figure 10). currents are often twice as large, and the circulation pattern is dramatically different. As the water moves offshore along the coast north of Boston, cold-nutrient rich water is upwelled as evident in the model, as well as in remotely-sensed images of sea surface temperature (Figure 13). Being able to model this type of response is especially important for understanding the proposed outfall's impact, as the outfall plume may be trapped in the cold, light-limited, deeper waters until it is upwelled.

Although the Massachusetts Bays do not have any large rivers that discharge directly into them, the Merrimack River just to the north of Cape Ann plays an important role in driving their circulation, especially in the spring (Butman, 1975). In the absence of wind, fresh water discharged from the river mouth forms a surface plume which turns to the right and follows the coast in the northern hemisphere. Thus the Merrimack and other Gulf of Maine rivers combine to generate a buoyancy-driven coastal current which flows southward off Cape Ann. Large river runoff events can drive currents with magnitudes of 20-40 cm/s in the bays, comparable to strong wind events.

Wind and river effects often interact nonlinearly, generating extremely complex flow patterns, even for fairly simple forcing functions. As an example, "turning on" the Merrimack River under the influence of a mean wind from the west gives rise to lateral and vertical salinity gradients that act with the wind and local topography to yield small-scale lateral eddying structures in Western Massachusetts Bay that change markedly with time and position in the water column (Figure 14). This illustrates the difficulty with isolating different forcing mechanisms from field data. Often, the mechanisms cannot be linearly superimposed. Numerical models frequently become the only viable mechanism for analyzing the transport of material when this is the case.

3.3 Outfall Plume Dynamics

Because of the complicated nature of the circulation in embayments such as the one considered here, it is difficult to make simple calculations based on observations regarding the transport of material suspended or dissolved in the water column. In particular, it is clear that realistically modeling the effluent plume from the proposed outfall requires a three-dimensional model that actively couples the density field with the

circulation. Because the plume is buoyant and may enter a stratified system, the model must have the ability to allow the effluent to become trapped below the thermocline or to rise to the surface as determined by the ambient stratification. This is critical, as the surface above and below the thermocline are often moving in opposite directions. Consider the movement of a plume produced through the discharge of $15 \text{ m}^3/\text{s}$ of freshwater into a well mixed Massachusetts Bay with a salinity of 32 psu. A steady wind stress of 1 dyne/cm^2 (about 7 m/s) yields the flow patterns shown on Figures 8 and 9 and also causes a complex plume structure (Figure 15). As the plume rises to the surface, it is advected northwestward by the bottom currents. However, as the plume approaches the surface, it is advected with the oppositely directed surface currents to the southeast.

4. FUTURE DIRECTIONS AND CONCLUDING REMARKS

Our knowledge of the processes affecting the movement and mixing of water masses, various chemical constituents and particles and our abilities to model them numerically has expanded considerably in the past five years. Hydrodynamic models of the coastal ocean have become indispensable aids in decision-making relating to wasteload allocations from point sources of pollution and to the design and licensing of offshore structures. The models typically are at their best in predicting phenomena related to the tides and to the response of the waters to local forcing conditions. However, strict attention must be given to the adequacy of the model grid spacing because experience has shown that when the model resolution is commensurate with the physical process of a region, the model simulations agree best with the observations.

It must be mentioned that the most critical factor limiting the development of truly predictive models is an understanding of the complex interaction between the coastal waters and those of the offshore ocean. Typically, coastal ocean models cover a limited region along the coast with their offshore extent ending at the continental shelf break. At this edge, it is necessary to introduce a boundary condition which must properly parameterize the influences of the ocean exterior to the coastal region being modeled. The use of both high quality data sets and specially designed numerical model experiments are needed to determine the proper feedbacks between the two regions.

Advances in computer power and speed have recently made it feasible to construct and apply time-varying, 3D hydrodynamic models. This type of modeling, while feasible, is computationally intensive and puts severe constraints on the resources available for engineering analyses. What is needed are models which include all the important physical, chemical and biological processes yet can be used in a time effective manner without significantly depleting the available computer resources. One approach to this problem is through the development of a hydrodynamic and water quality model interfacing methodology which will produce coarse spatial resolution, time averaged, residual transports from a high spatial resolution, intratidal hydrodynamic model. These time and space averaged mass transport quantities should be sufficient to drive appropriate segmented water quality models without loss of accuracy.

Finally, there is a need to make better use of available observations. Models require data to establish interior and boundary conditions, to update boundary fields, to validate the model physics and to verify the

simulations. Current, temperature and salinity data are often insufficient for an unambiguous model calibration/validation and one must look at how well the water quality constituents are being modeled to derive a sense of the validity of the modeled transport processes. One needs to blend the results from both circulation and water quality models with the available data to provide for the best estimates of how water and materials are transported throughout a coastal system. The data assimilation, that is, the process of this blending, is undoubtedly the most powerful tool presently available for extracting information and insight from the sparse coastal ocean data sets and the imperfect model results.

5. ACKNOWLEDGEMENTS

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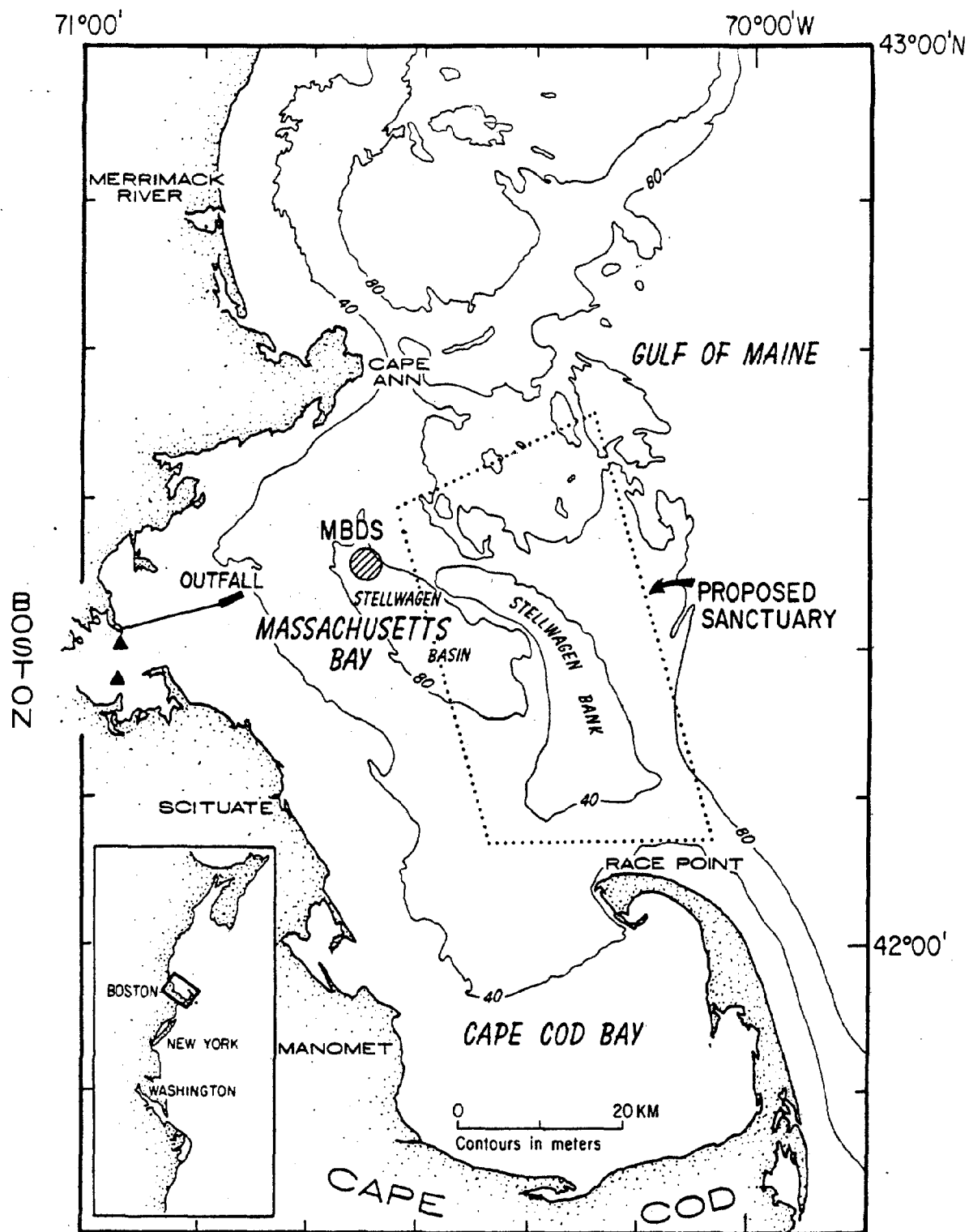


Figure 1. Bathymetric map showing Massachusetts and Cape Cod Bays, present sewage outfalls in Boston Harbor (solid triangles), location of new ocean outfall for treated Boston sewage in western Massachusetts Bay (average flow about $20 \text{ m}^3/\text{s}$), approximate boundary of the proposed Stellwagen Bank Marine Sanctuary, and the Massachusetts Bay Disposal Site (MBDS). The annual volume of river discharge from the Merrimack is about $215 \text{ m}^3/\text{s}$ and through Boston Harbor is about $10 \text{ m}^3/\text{s}$, from Butman et al (1992).

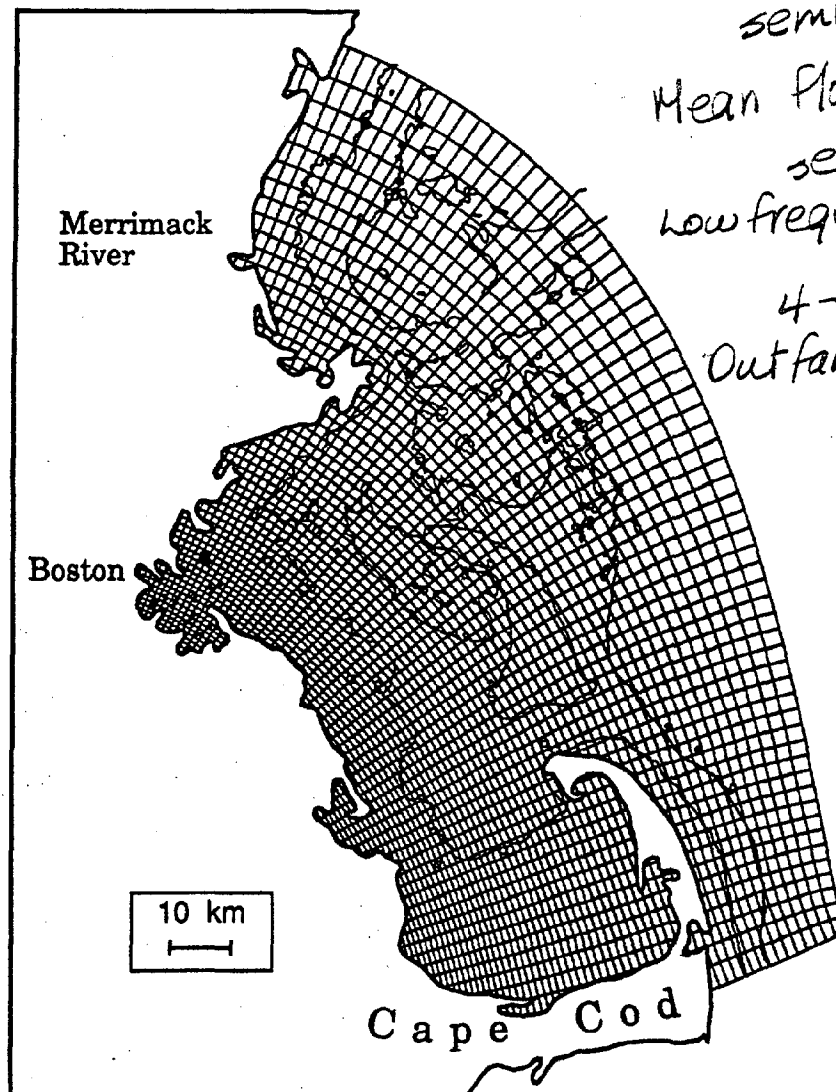


Figure 2. Model grid for the three-dimensional circulation model, ECOM3D, of Massachusetts and Cape Cod Bays. The curvilinear orthogonal grid allows the mesh resolution to vary spatially, having a minimum grid spacing of 600 m and a maximum spacing of 6000 m. The grid spacing in the vicinity of the proposed outfall is roughly 1000 m. There are currently 10 vertical σ -levels in the model, evenly spaced throughout the water column.

Tidal Currents

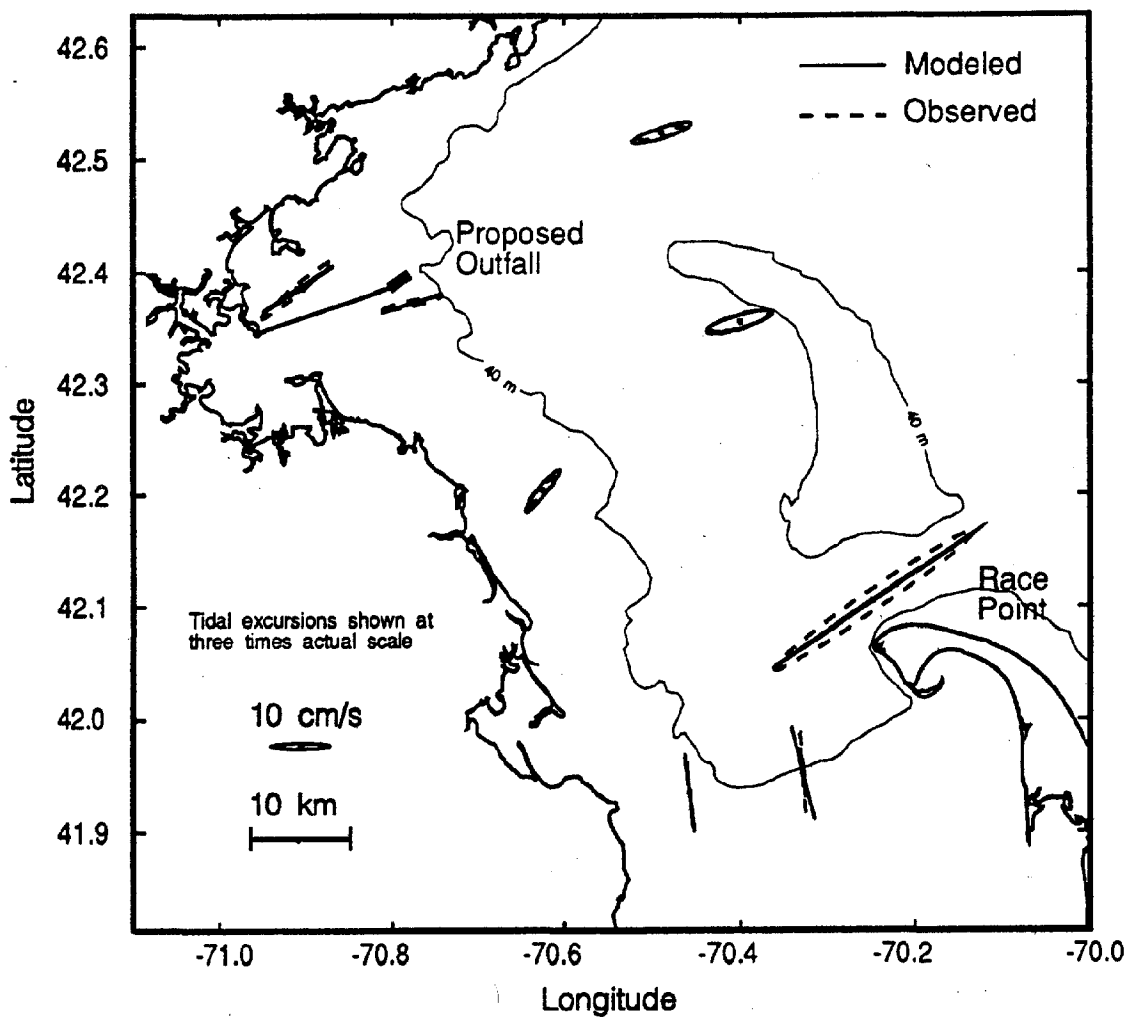


Figure 3. Comparison of modeled and observed surface M_2 barotropic tidal currents in Massachusetts Bay. Shown are tidal ellipses, which indicate the observed velocities over the tidal cycle. They also represent the excursions water parcels would make if they moved with the tidal currents observed at the mooring. For clarity these tidal excursions are shown at three times actual scale. Tidal excursions are nearly 10 km off Race Point, but only 2 km near the location of the proposed outfall.

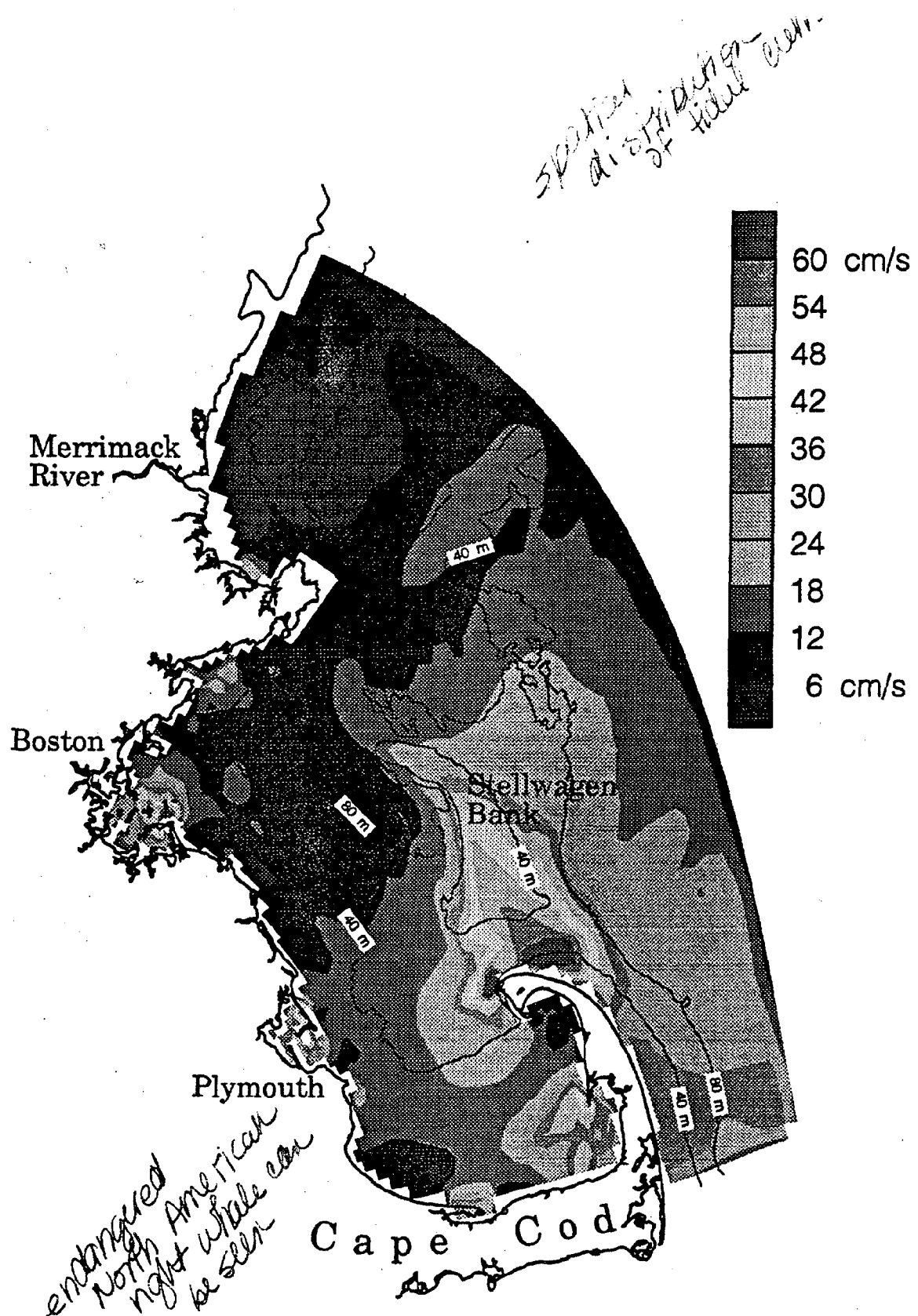


Figure 4. Maximum tidal current speed at the surface. Currents are strongest off the tip of Cape Cod and in the entrances of smaller embayments such as Boston and Plymouth Harbors. Strong gradients in the tidal current speed are found on Stellwagen Bank and around the tip of Cape Cod, and coincide with regions where Right Whales are most likely to be found (Hamilton and Mayo, 1988).

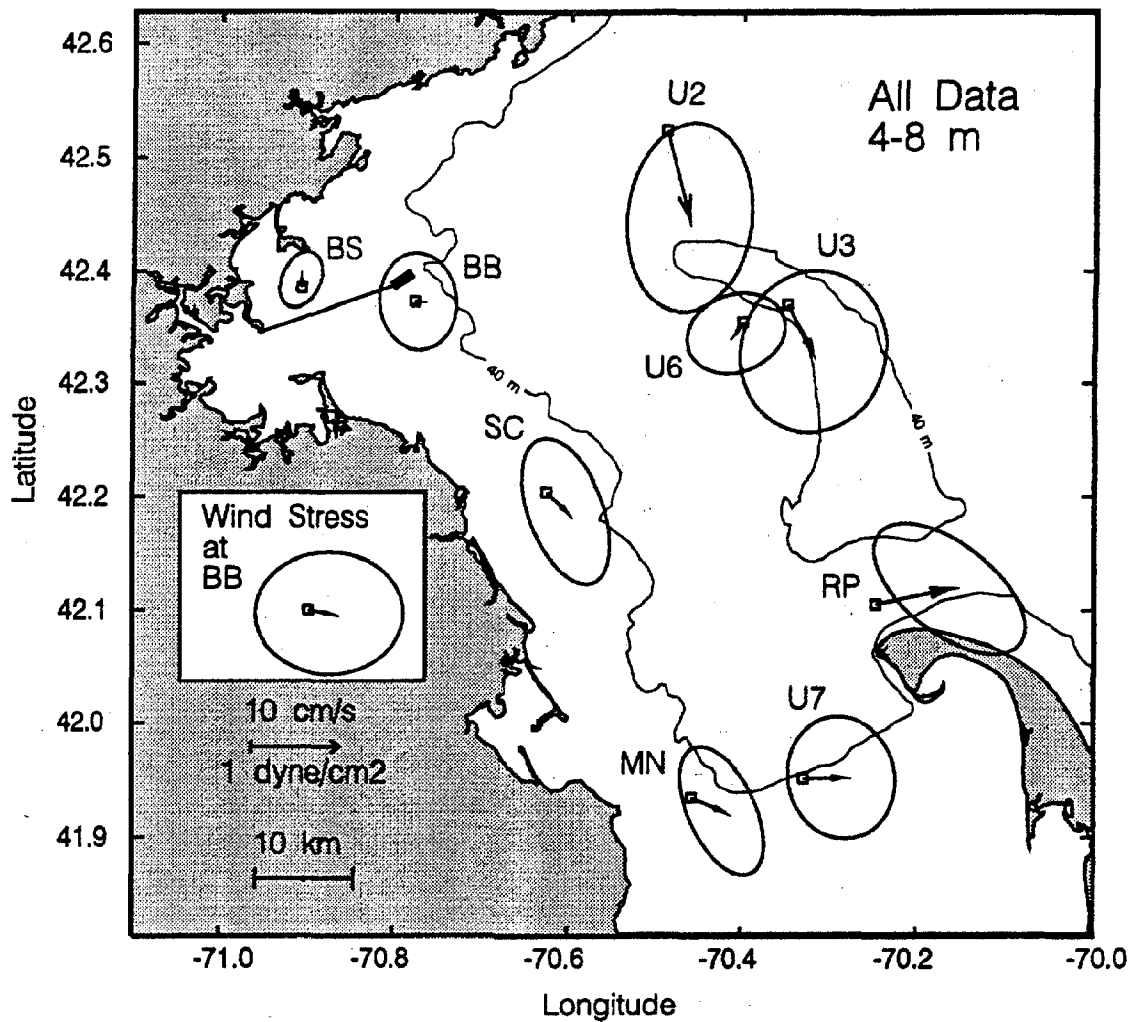


Figure 5. Map showing the mean flow (solid arrow) and the low frequency variability (shown as ellipses centered around the tip of the mean flow) for all near-surface (4-8 m depth) current measurement made from December 1989 to September 1991. The daily averaged currents originates at the station symbol and flows toward any location within the ellipse. The arrows and ellipses have been scaled to correspond to the distance a particle moving with that current would travel in one day, Butman et al., (1992).

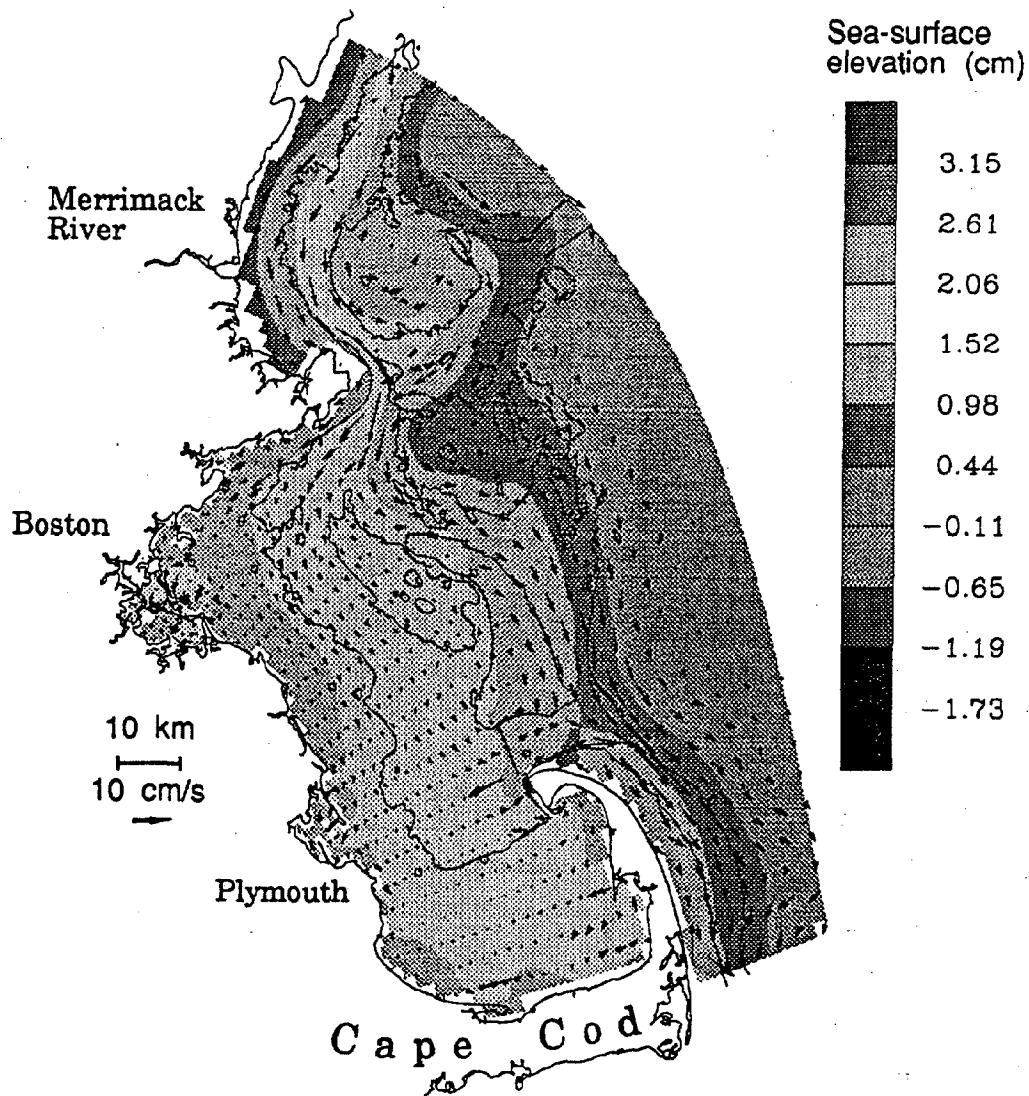


Figure 6. Modeled surface current and elevation response to the Gulf of Maine coastal current. The results suggest that much of the coastal current "misses" Massachusetts Bay, flowing to the east of Stellwagen Bank following the isobaths. The coastal current explains the observed mean flow southeast of Cape Ann and at Stellwagen Bank (stations U2, U3 and U6 in Figure 5).

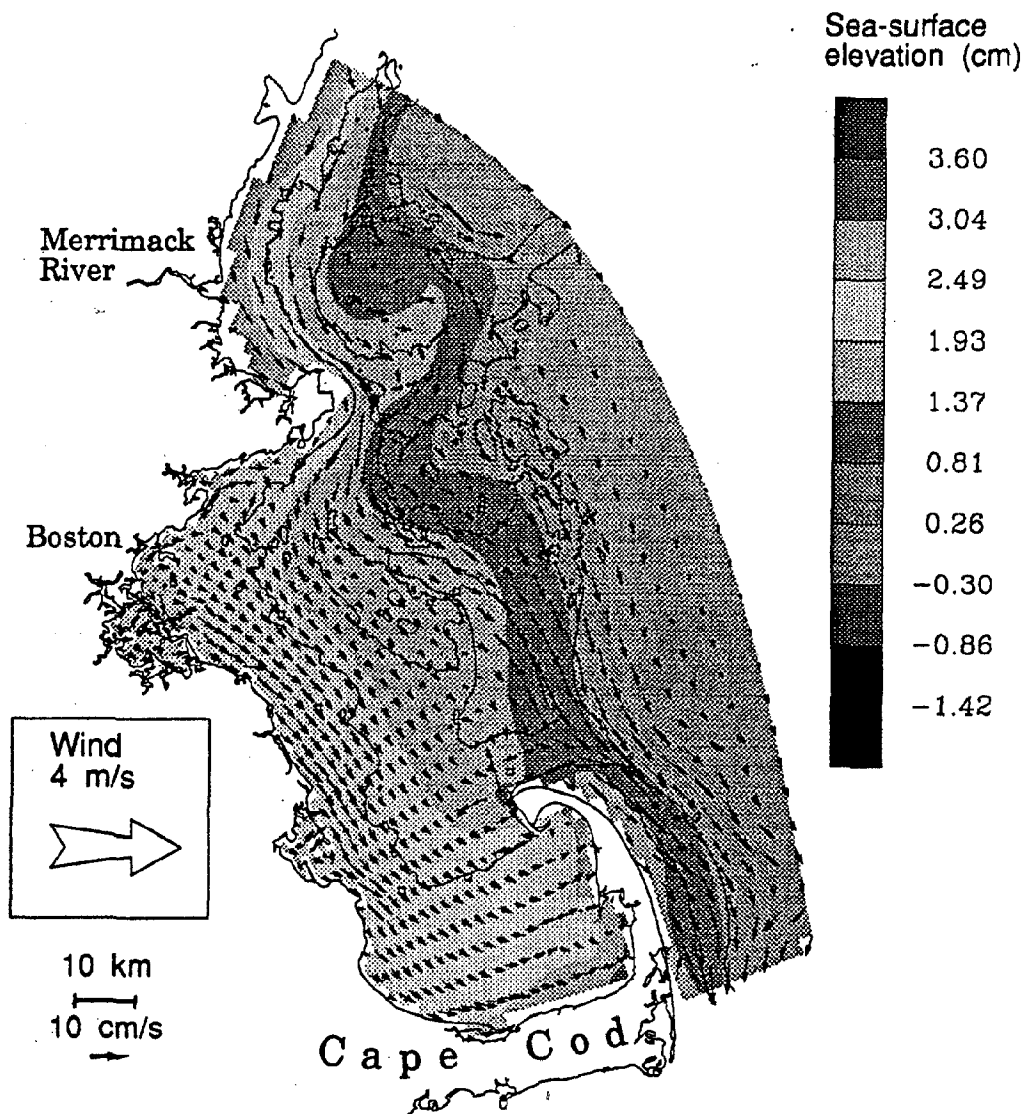


Figure 7. Modeled surface current and elevation response to the Gulf of Maine coastal current and the mean wind stress. Adding the mean wind stress to the forcing from a coastal current dramatically improves the simulation of the mean flow, driving a southeastward current along the coast from Boston to Cape Cod which exits the bays at Race Point.

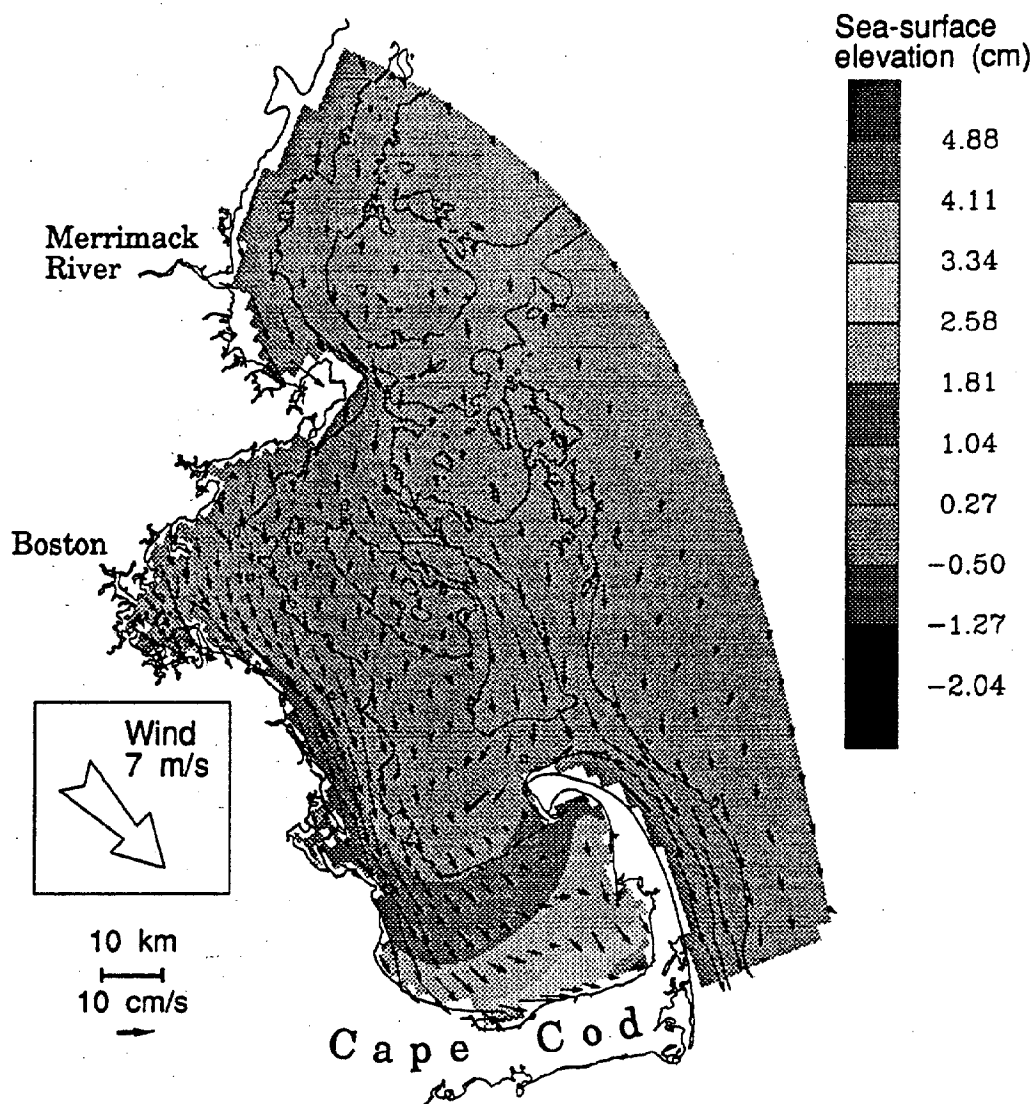


Figure 8. Modeled surface current and elevation response to a wind stress from the northwest of 1 dyne/cm^2 (about 7 m/s) in well-mixed conditions. This alongbay wind drives strong flow downwind in the shallow water near the coast. The convergence of surface water along the northern shore of Cape Cod indicates the presence of strong downwelling.

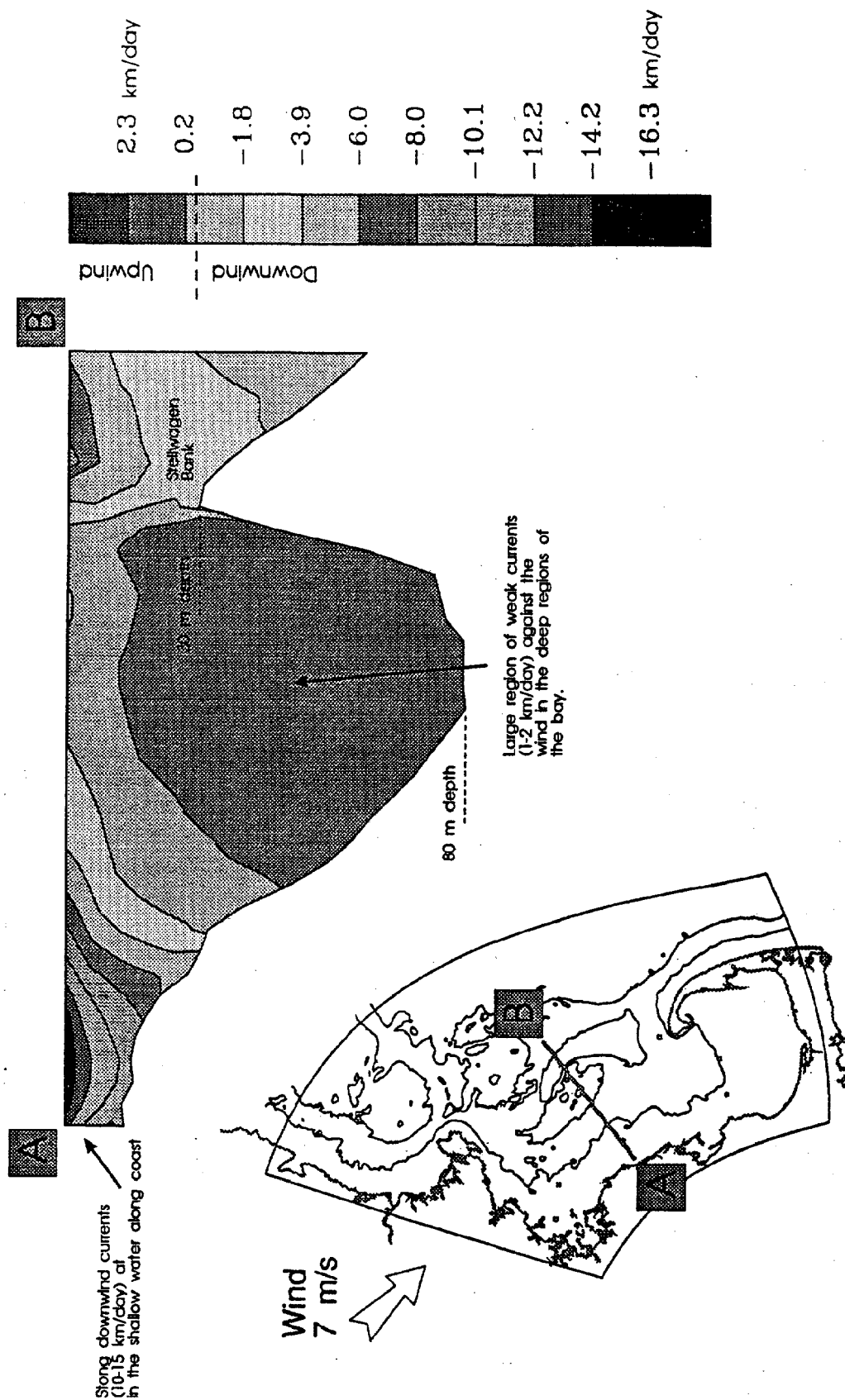


Figure 9. Vertical section of along-bay current response to wind stress from the northwest of 1 dyne/cm^2 (about 7 m/s) in well-mixed conditions. The alongbay wind drives downwind currents of $10\text{--}15 \text{ cm/s}$ in the shallow water near the coast. The downwind current established an opposing pressure gradient, which drives a weak return flow ($1\text{--}2 \text{ cm/s}$) at depth.

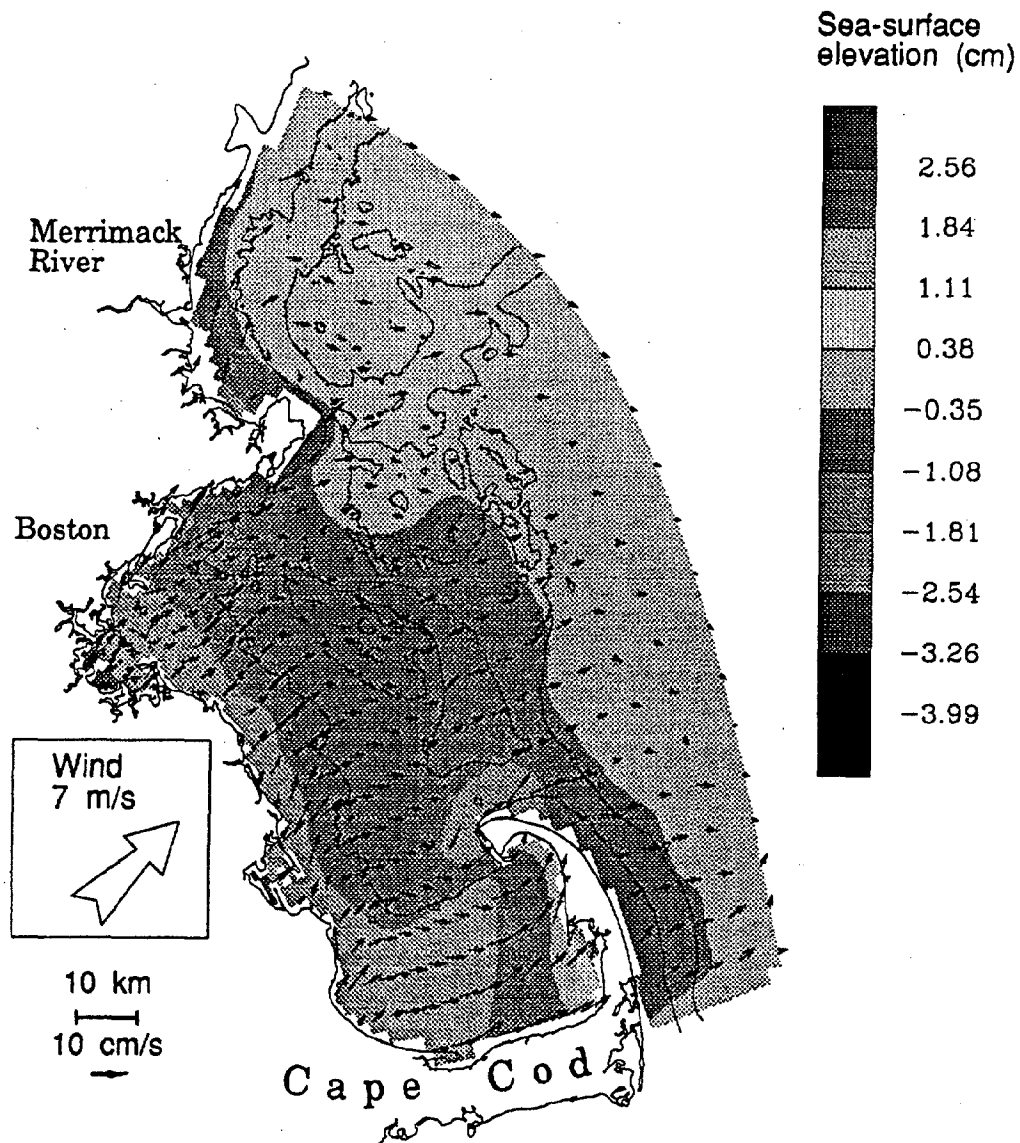


Figure 10. Modeled surface current and elevation response to a wind stress from the southwest of 1 dyne/cm^2 (about 7 m/s) in well-mixed conditions. The cross-bay wind drives downwind surface flow of nearly the same magnitude over most of the Massachusetts Bays. The currents near the coast are significantly weaker than those generated by the alongbay wind shown on Figure 8.

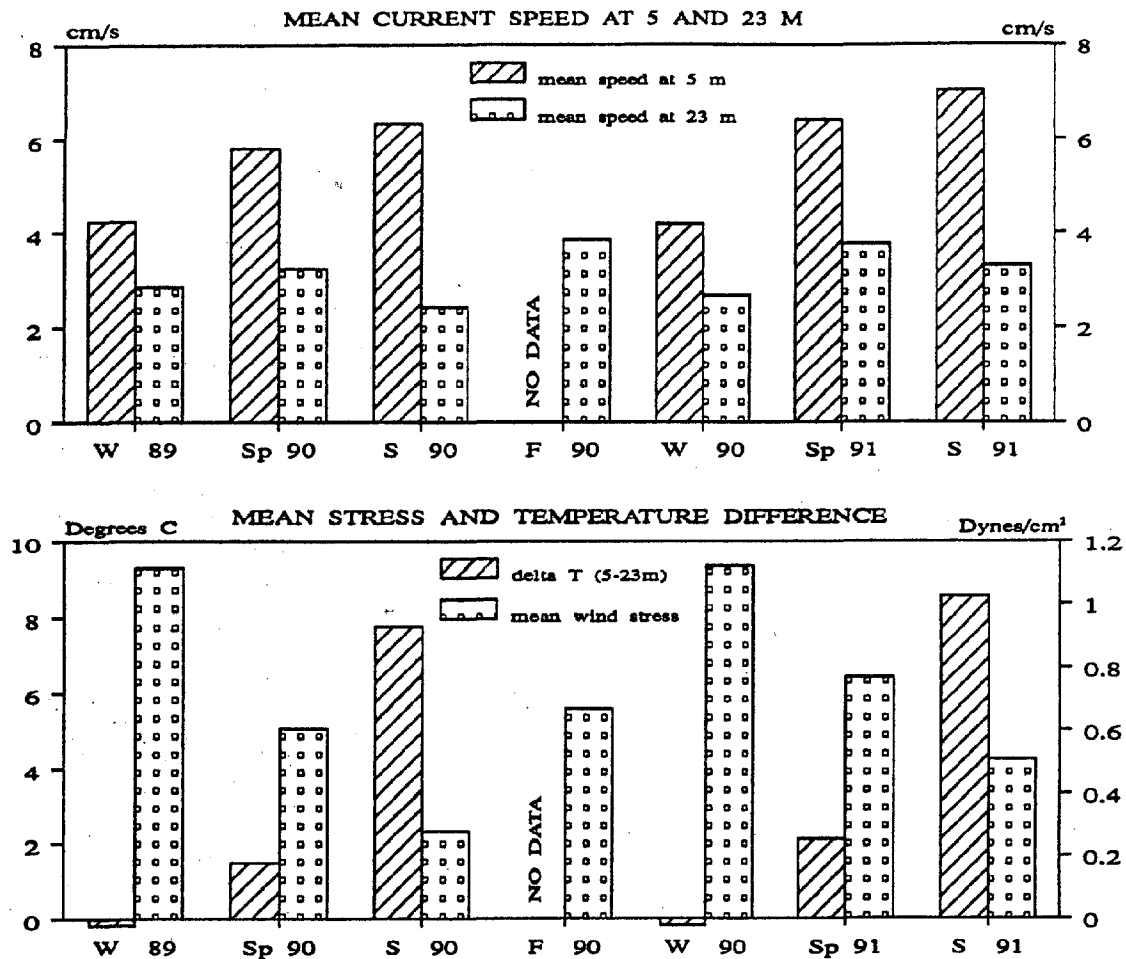


Figure 11. Top: Mean daily vector-averaged current speed at Station BB (Figure 5) at 5 and 23 m water depth (winter, November through February; spring, March through May; summer, June through August; fall, September and October). Bottom: Mean daily averaged wind stress amplitude at the Large Navigational Buoy and temperature difference between 5 and 23 m water depth. These data suggests that stratification is more important than wind in determining the strength of the near-surface current at the new outfall site.

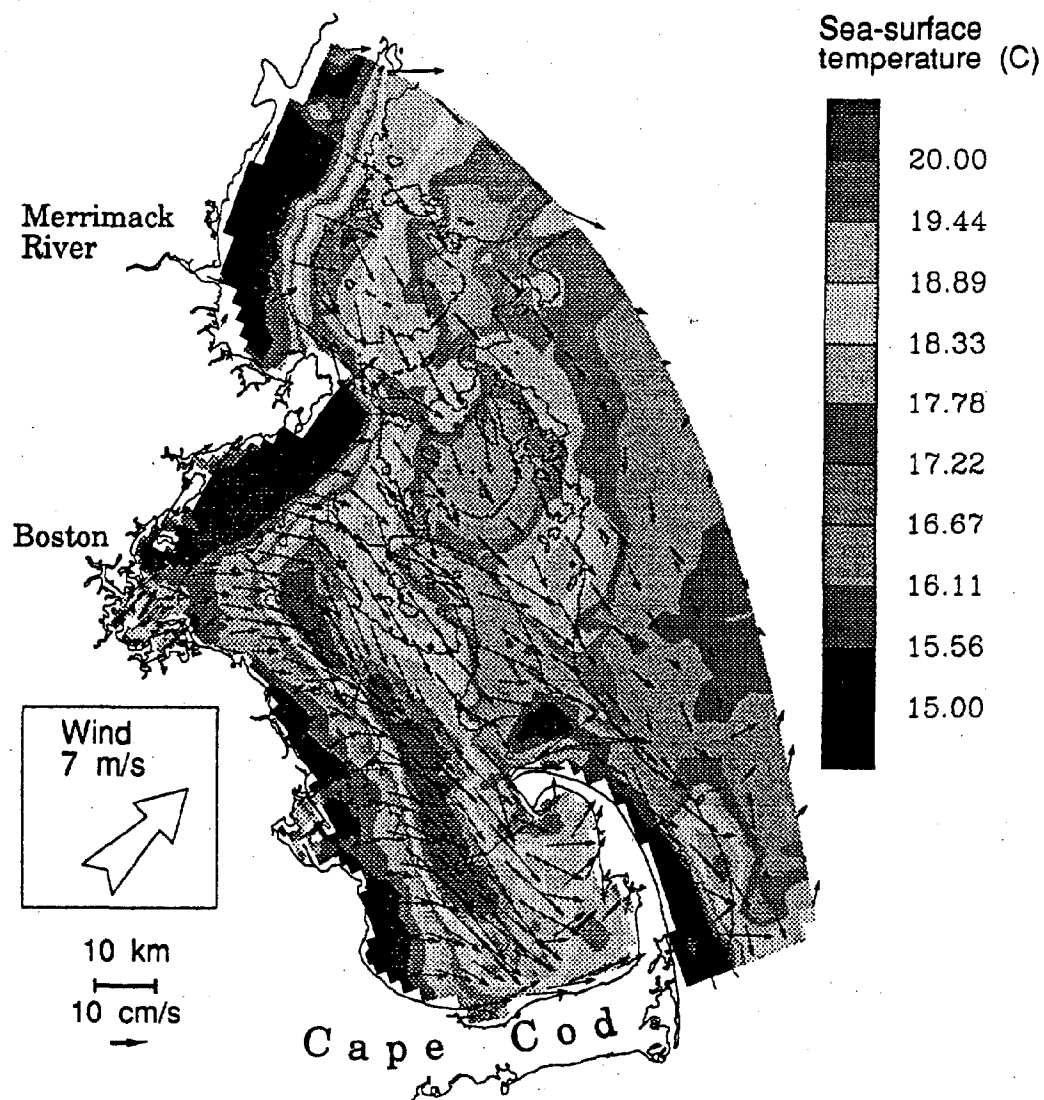


Figure 12. Modeled surface current and sea-surface temperature response to a wind stress from the southwest of 1 dyne/cm^2 (about 7 m/s) in stratified conditions. From a homogeneous state, the model was run with M_2 tides and a surface heat flux of 100 W/m^2 for 12 days. The wind was imposed for the last two days of the simulations. The wind induced upwelling brings cold nutrient rich water from depth to the surface and plays an important role in primary production.

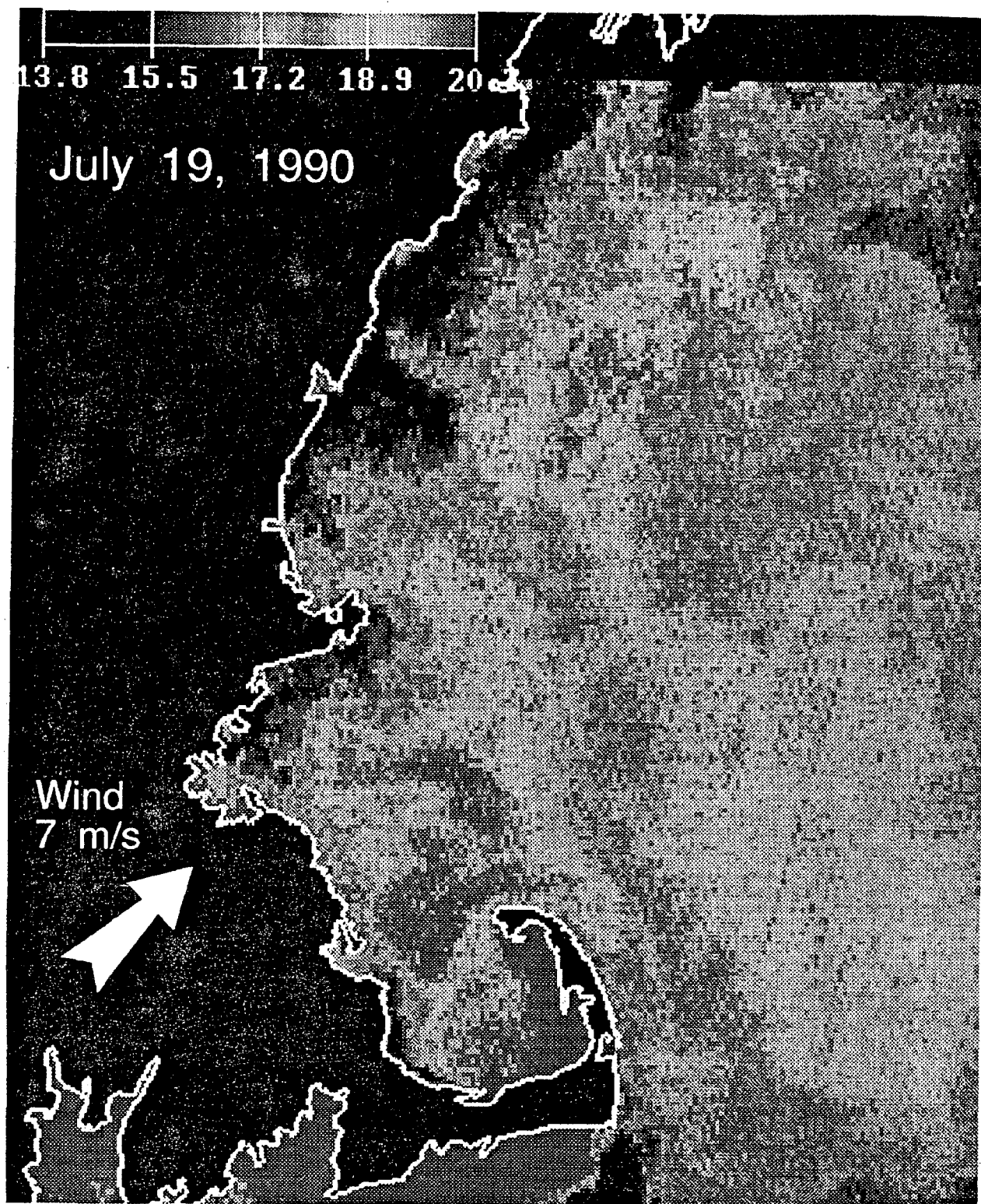


Figure 13. Observed sea-surface temperature during a typical summer upwelling event, at 0600 on July 19, 1990. For the preceding two days, the wind was relatively constant at a speed of about 7 m/s from the southwest. The observed surface temperature patterns are quite similar to the modeled upwelling event, especially along the coast (Figure 12).

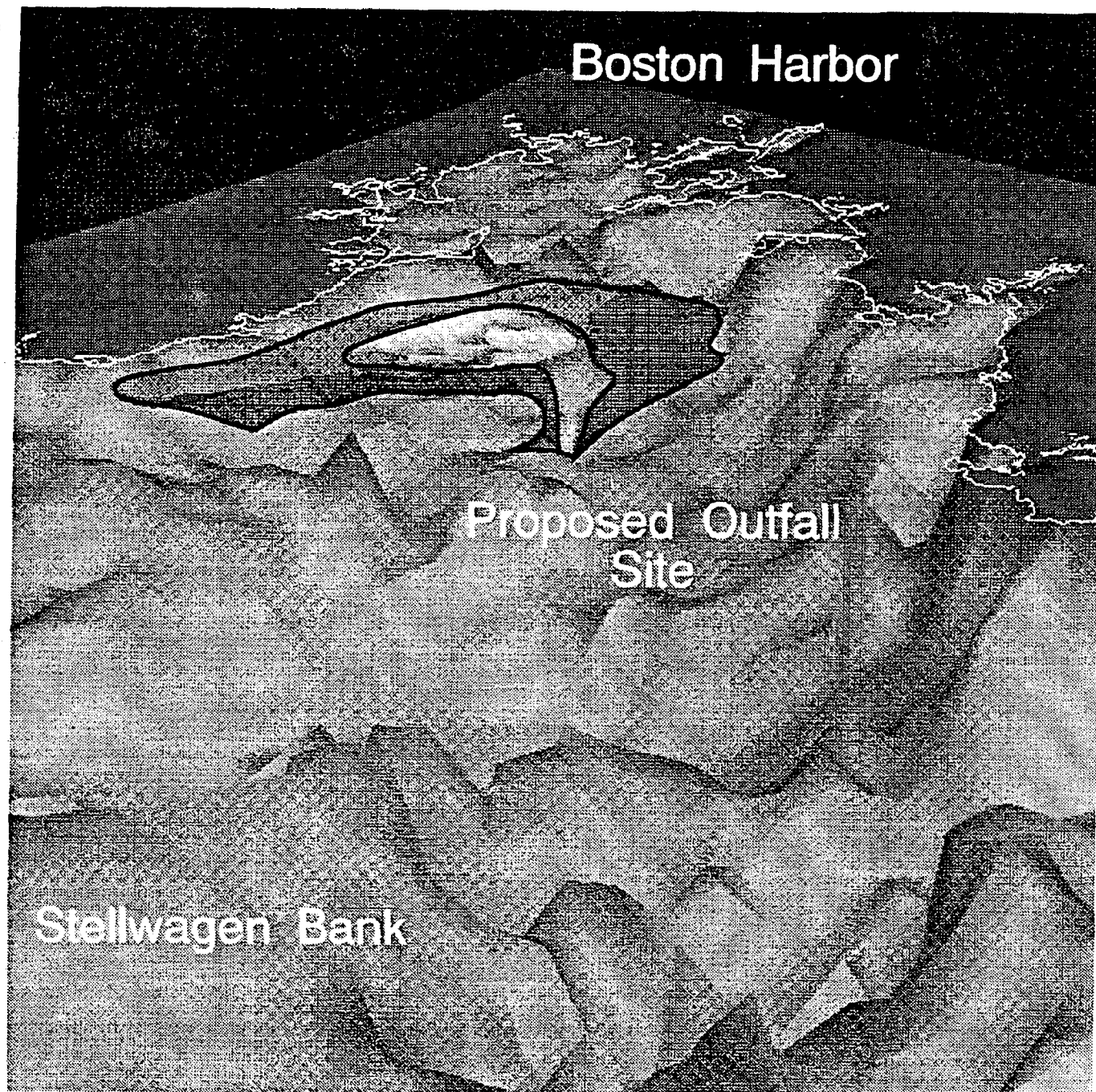


Figure 15. Three-dimensional view of the plume caused by a discharge of $15 \text{ m}^3/\text{s}$ of fresh-water at the proposed outfall site under well-mixed conditions. A wind stress of 1 dyne/cm^2 (about 7 m/s) was applied from the west, and shown are dilution isosurfaces of 250 and 500 after 9 days of simulation. As the plume rises to the surface, it is pulled toward Boston by the bottom currents, but when it reaches the surface it moves with the surface currents and is transported along the coast toward Cape Cod.

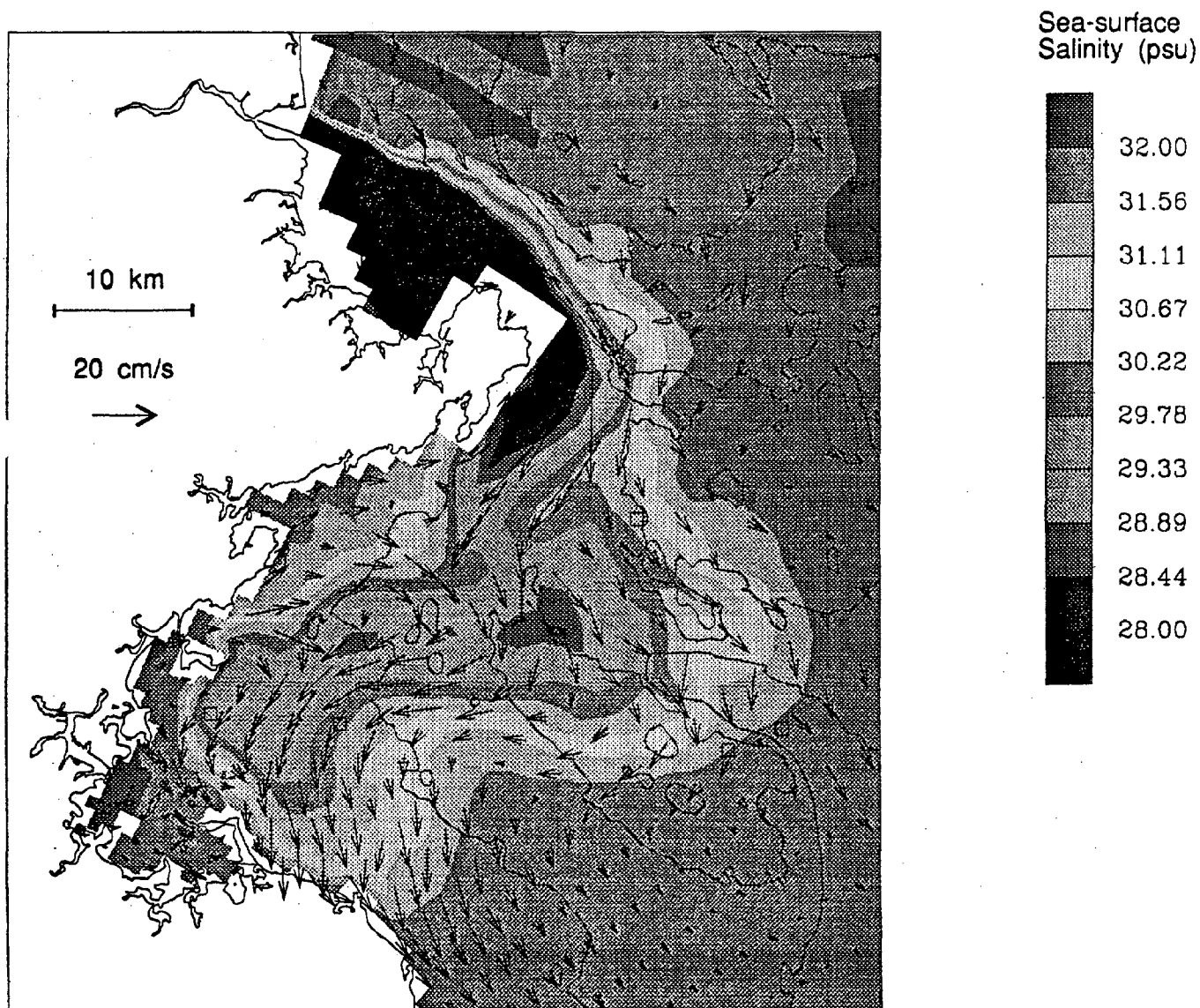


Figure 14. Modeled surface current and salinity response of western Massachusetts Bay to a runoff event from the Merrimack River. The Merrimack was "turned on" with a flow of 500 m³/s, a magnitude typical of a spring freshet (Geyer, 1992), and shown is the result after 8 days. The runoff event creates strong and complex currents in the vicinity of the proposed outfall site which would be difficult to resolve with moored instruments.

COASTAL GEOMORPHOLOGY

A Paper Presented at
CGER Coastal Zones Retreat
National Research Council
National Academy of Sciences

Woods Hole Study Center
Woods Hole, Massachusetts

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accommodate (e.g., raise buildings to the projected higher flood levels); or (3) protect (build hard or soft structures). In areas of dense population and highly developed infrastructure, protection is the preferred alternative. Hard structures are costly and inflexible, and often have environmentally and aesthetically undesirable effects such as loss of the recreational beach. Thus, beach nourishment has become the coastal management "tool of choice" over the last several decades (National Research Council, 1987; Leatherman, 1991).

To date, over 640 km (400 miles) of U.S. coastline have been nourished, largely through public funding, at a total cost of about \$8 billion (Dixon and Pilkey, 1989). Overseas, beach nourishment has become very popular, particularly in developed countries such as Denmark, the Netherlands, Australia, and Great Britain (Delft Hydraulics, 1987), but also in developing countries such as Brazil (Vera Cruz, 1972) and Nigeria (Ibe et al, 1991).

The use of beach nourishment as a coastal management tool will probably continue its significant growth over the next few decades. However, the contemplated economic commitments to this management alternative by federal, state, and local governments is unprecedented. For instance, in northern New Jersey a Congressionally authorized nourishment project proposes to reinstate 19 km (12 miles) of beach at a cost of approximately \$200 million with projected maintenance costs over 50 years of about \$300 million (Bocamazo, 1991). Similarly, the total cost

of the recently (1991) completed Ocean City, MD, nourishment project, including renourishment every four years for 50 years, is estimated at \$342 million (Kelly, 1991).

In spite of this increasing use, our understanding of the performance of beach nourishment is still poor. This lack of understanding is because: (1) predictive models of beach behavior in response to varying hydrodynamic forces are still relatively crude tools for engineering purposes; and (2) most completed projects did not include adequate post-emplacement monitoring to allow for objective project assessment and necessary adjustment of designs. With our present understanding, each beach fill remains, in part, an educated experiment. Although many believe that there is sufficient understanding and inherent flexibility within the procedure to produce practical and successful designs (Delft Hydraulics, 1987), this confidence is not universally accepted.

During the 1980s, because of the actual or perceived failure of numerous projects, beach nourishment began receiving heavy criticism as an ill-advised use of taxpayers' money (e.g., Gilbert). During this time, Pilkey and others (e.g., Leonard et al, 1989) began to contradict the traditional coastal engineering methods used to design and evaluate such projects. Such criticisms are not isolated, and many coastal environmental groups advocate planned retreat as the only true solution to coastal erosion.

The conclusions of Pilkey et al. have been challenged by many in the scientific and engineering communities (e.g., Strine and Dalrymple, 1989; Houston, 1991a). Nonetheless, contentions from the Pilkey camp have focused attention on the lack of high quality monitoring of U.S. beach nourishment projects and acted as a catalyst for renewed research efforts. This controversy places beach nourishment in the forefront of public policy decisions in the coastal zone.

For governments attempting to promote taxes, bond referendums, or otherwise raise money for beach nourishment, or for those jurisdictions that have already funded projects, accurate designs are essential for predicting beach fill longevity and maintenance requirements. The basic aim of beach nourishment is to advance the shoreline a given distance and hence realize all the consequent benefits such as increased storm protection. The impressive coastal accretion at sites where mining waste is dumped directly into the sea clearly demonstrates that if enough sand/gravel is placed on a shoreline, a substantially wider subaerial beach can be created (e.g., Paskoff and Petiot, 1990). However, beach nourishment demands quantitative understanding of this process, particularly what volume and grain size of sand is required to attain a specific increase in subaerial beach width and what is the lifetime, and hence the renourishment frequency of that beach (e.g., Dean and Grant, 1989).

However, as characterized by numerous workers and summarized by Delft Hydraulics (1987), many of the present design concepts remain relatively untested against actual field performance: "an exact forecast of the behavior of the beach fill is not possible, not even in the case where a large number of data of the relevant areas is available." Egense and Sonu (1987) reiterate as follows: "At the present stage of technology, beach nourishment is more art than science." The behavior of nourished and natural beaches is subject to the same uncertainties, and Wiegel (1987) argues that our present inadequate quantitative knowledge of natural beach processes handicaps dependable estimates on how well nourished beaches will perform. From a fundamental perspective, future shoreline evolution will always be stochastic, even with complete understanding of all the processes, as the underlying driving forces (waves, storms, etc.) are themselves stochastic (National Research Council, 1990). Thus, probabilistic predictions of nourishment performance must be the goal. When combined with high precision monitoring, this will provide all the information required to successfully and optimally plan and implement beach nourishment.

Evaluation of beach nourishment projects requires knowledge of sand transport limits as well as delineation of the profile of equilibrium; these are fundamental concepts in coastal geomorphology (Leatherman, 1991). It is not often appreciated that most of the active beach profile is submerged. The entire profile must be moved seaward for nourishment to be successful.

Thus, the seaward limit of the active beach profile for the purposes of beach nourishment is a problematic but very important determination (Bruun, 1986; Hansen and Lillycrop, 1988). Early nourishment projects did not consider the offshore profile (Jarrett, 1987), or if they did, utilized unrealistic slopes which caused excessive losses of the subaerial beach (Hansen and Lillycrop, 1988). Hallermeier (1981) developed a wave-based profile zonation, including the depth definitions; field observations support this recommendation (Houston 1991b; Hands, 1991), and the equilibrium profile concept can be applied to beach nourishment design (Dean, 1983; 1991). But clearly more field data are required, and routine post-project monitoring should include measuring the entire active profile to the depth of closure. Such basic data as time-series surveys of beach profiles are difficult or impossible to obtain for most of the 155 nourished beaches considered by Pilkey et al. Therefore, the effectiveness of beach nourishment projects, particularly actual versus predicted performance, is debatable, and substandard sources, such as the local media, have been used to declare project "success" or "failure".

Another problem involved in assessing the performance of beach nourishment is the widespread lack of post-project monitoring by independent, objective parties. It has often been said that having the U.S. Army Corps of Engineers monitor their own projects is akin to "having the fox guard the hen house".

This situation can be easily remedied by using the wealth of available talent of universities and private consultants.

There is also frequently a lack of commitment or inability of project sponsors to properly maintain nourished beaches. This raises important questions about the accreditation of beach nourishment projects, particularly when using such projects as a means to potentially lower 100-year flood levels and hence to reduce the cost of federal flood insurance. Also, many states now petition FEMA for funds to restore their eroded beaches after a coastal storm. Clearly there needs to be established criteria for design, maintenance and financing requirements for the accreditation of beach nourishment projects.

These and other accreditation criteria (e.g., Dean and Grant, 1989) are probably a progenitor for the treatment of beach nourishment by existing state programs and by a pending federal erosion management program that encourages building setbacks with the incentives of Federal flood insurance (National Research Council, 1990; Davison, 1992). However, long-term financial commitments by project sponsors; limited offshore sources of economical beach quality sediment; project performance guarantees; assurances for immediate post-storm reconstruction; and other problematic issues regarding accreditation of beach nourishment (not to mention hard structures) in determining erosion rates are questions which, given our present scientific knowledge, and the uncertainty of future political decisions,

cannot be easily answered. Again, this reiterates the need for standardized post-placement monitoring.

The increasingly developed character of the world's coastline will undoubtedly lead to increasing demand for beach nourishment. Hopefully this will be undertaken within the context of sensible management plans that plan for sustainable use of the coastal zone (IPCC, 1990). In addition to population and development pressure, accelerated sea-level rise will also increase the demand for beach nourishment (Weggel, 1986; Leatherman and Gaunt, 1989). This raises a number of new questions, particularly the seaward limit of the beach profile over long timescales and the long-term availability of sufficient sand. Innovative design methods utilizing structures to forestall fill losses may become necessary (Weggel, 1986). Undoubtedly, these issues will receive considerable attention in the coming decades.

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Introduction and Extended Outline: *

Rivers and Estuaries - A Hudson Perspective

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INTRODUCTION

The perspective of this paper and the specific examples used for illustration reflect the fact that the principal author has spent much of the past fifteen years involved in geochemical research on the Hudson River and contiguous waters. The general observations should be broadly applicable to rivers and estuaries and provide a basis for further discussion.

The initial announcement of the retreat proposed a goal of "approaching broad resource and environmental issues somewhat more holistically than our sometimes more piecemeal efforts." The Hudson is an excellent candidate for such coordination. Present federal research on the system includes a Superfund project to "reassess" the PCB problem (EPA); the New York-New Jersey Harbor Estuary Program (EPA); involvement in the NOAA National Status and Trends Program; studies of its tidal marshes as part of the National Estuarine Sanctuaries Program (NOAA); and USGS studies as part of their National Water Quality Assessment (NAQWA) Program. Additional research funds, on the order of a

* Full manuscript will be forthcoming or handed out at retreat.

million dollars a year, are supplied by a private foundation, the Hudson River Foundation. State and city efforts, policy and regulatory considerations, and active participation of environmental groups such as NRDC and EDF add to the challenge of arriving at a holistic approach. It seems that a logical initial step in this direction involves a consideration of research needs and directions. Past experience on the Hudson suggests the following:

BASIC INFORMATION -

There is a need for continuous long term monitoring of salinity and suspended matter concentrations. On the Hudson there are two stations where suspended matter concentrations are measured daily - both are upstream of the first dam (!).

TRENDS AND THE CURRENT SITUATION-

1) Particle Associated Contaminants - A most useful tool is the analysis of dated sediment core sections to develop contaminant chronologies. More emphasis should be placed on analysis of "current" particle samples. These can be suspended particle samples or core top samples identified by their content of short-lived radionuclides.

These types of studies can be useful for determining the response time of rivers and estuaries to pollution events, for locating major sources of contaminants, for tracing net particle transport in estuaries and for determining in situ rates and pathways of organic contaminant degradation. Archiving of dated

sediment core samples is suggested.

2) Nutrients - There is a need for greater commitment to long-term, research-based monitoring. Basic information on the response of the estuary to major changes in sewage treatment is available only as a result of creative use of piecemeal funding over the past fifteen years.

RESEARCH AND REGULATION-DRIVEN MONITORING

If undertaken, this will be a most difficult marriage. There is, however, significant potential for collaboration. For example:

The New York City Department of Environmental Protection has regular cruises on the lower Hudson. Participation of research scientists would make more efficient use of the ship time.

Regulation-driven monitoring practices could be altered to provide useful research information. Information on time of deposition could be obtained on sediment samples collected for contaminant-level monitoring; analytical procedures and sample sizes could be adjusted to provide some real data on selected contaminant inputs from sewage treatment plant effluents.

Most of the original wetlands bordering the lower Hudson have been filled. Future development will require groundwater monitoring at many of these sites. Integration of research studies would be a cost-effective means of providing basic information on coastal groundwater systems.

OTHER SPECIFIC RESEARCH AREAS

Gas Exchange - Models of atmospheric oxygen inputs and nitrous oxide export from estuaries generally relate turbulence to wind speed, tidal flow, or the relatively few direct measurements that have been made. Recent work in lakes using injected tracers shows great promise for direct determination of gas exchange. In estuaries, injection of freons with sewage treatment plant effluent may provide an extremely useful gas-exchange tracer.

DOC/Colloidal Particulates - The high temperature catalytic oxidation technique has stimulated interest in oceanic DOC. In estuaries, DOC/Colloidal Particulate geochemistry is rather poorly understood. We do know that it exerts significant influence on trace metal and organic contaminant behavior. Additional study is indicated particularly in the area of real system measurements.

Fine-Particle Behavior in the Coastal Environment - What is the fate of fine particles and associated contaminants flushed from estuaries during high discharge events ? What fraction is deposited on the shelf ? Is there significant transport to the deep ocean ? To what extent do estuaries act as particle traps ? These basic and very significant questions are amenable to study with geochemical tracers. Some recent data on DDT-derived compounds in the coastal environment suggests that atmospheric inputs of unaltered DDT may provide a most useful tracer.

**TYPES OF COASTAL ZONE:
SIMILARITIES AND DIFFERENCES**

by

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Coastal and estuarine waters are the parts of the sea that overwhelmingly dominate our everyday affairs. Our rapidly expanding use of the ocean, increasing excursion upon it, and entry into it are mostly concerned with processes that take place in shallow water. Conversely, it is mostly within coastal waters that the human acts, such as waste discharge, fishing, dredging, mining, drilling, and coastal structures, have their greatest impact on the ocean. Accordingly, coastal waters and the underlying submerged lands are the areas of highest scientific interest and jurisdictional controversy.

This paper provides an overview of the world's five types of coastal zones. Their tectonic origins and shaping processes are compared and contrasted. An understanding of these different types of coasts and their nearshore processes is essential to policy making efforts.

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FACTORS DETERMINING COASTAL ZONE TYPES

The common types of coastal zone are well represented along the shores of the United States. These types range from the ice-push coasts of Alaska to the coral reef coasts of Hawaii and southern Florida and include, as well, the far more common types such as the barrier-beach coasts of the Atlantic, the steep, cliff-backed coasts of the Pacific and the marginal seas type coast of the Gulf of Mexico. Although there are general processes that apply to all coasts, there are also significant differences among coastal types.

These similarities and differences stem from the influence of various processes. The most important of these processes are:

1. tectonics
2. exposure to waves, winds and ocean currents
3. tidal range and intensity of current
4. supply of sediment and its transport along the coast
5. coastal climate

The position and configuration of the continental shelf and adjacent coast are related to the moving, tectonic plates. This geologic setting (1) and the exposure to waves (2) are the two most significant factors in determining nearshore processes. Waves, winds, and currents (2 and 3) are the principal driving forces for coastal processes, and have extensively modified the coast by the erosion and deposition of sediment (4). Coastal climate (5) is mainly dependent upon latitude and the location of the major ocean and atmospheric current systems. Extremes in coastal climate associated with latitude result in the unique aspects characteristic of arctic coasts in the north and coral reef coasts near the equator.

The tectonic and paleoclimatic processes important to the geologic setting of coasts operate over the largest areas and have the longest time scales. Since the large scale features of a coast are associated with its position relative to plate margins, plate tectonics provides a convenient basis for the first order classification of coasts, i.e., longshore dimensions of about 1,000 km (Inman and Nordstrom, 1971). Such a classification leads to the definition of three general tectonic types of coasts, (1) collision coasts, (2) trailing-edge coasts, and (3) marginal sea coasts.

Collision coasts are those that occur along a plate margin where the two plates are in

collision or impinging upon each other (Figure 1). Tectonically this is an area of crustal compression and consumption. These coasts are characterized by narrow continental shelves bordered by deep basins and ocean trenches. Submarine canyons cut across the narrow shelves and enter deep water. The shore is often rugged and backed by sea cliffs and coastal mountain ranges; earthquakes and volcanism are common. The sea cliffs and mountains often contain elevated sea terraces representing former relations between the level of the sea and the land (Figure 2). The west coasts of South and Central America are typical examples of collision coasts. Although much of the California coast is now a northward moving terrain associated with the San Andreas fault, this coast retains most of the characteristics of its collision history.

Trailing-edge coasts occur on the "trailing-edge" of a land mass that moves with the plate and are thus situated upon the stable portion of the plate away from the plate margins. The east coasts of North and South America are examples of mature trailing-edge coasts. These coasts typically have broad continental shelves that slope into deeper water without a bordering trench. The coastal plain is also typically wide and low-lying and usually contains lagoons and barrier islands as on the east coasts of the Americas (Figure 2).

Marginal sea coasts are those that develop along the shores of seas enclosed by continents and island arcs. Except for the Mediterranean Sea, these coasts do not usually occur along plate margins since the spreading center margins are commonly in ocean basins, while the collision edges of plates face oceans. These coasts are typically bordered by wide shelves and shallow seas with irregular shorelines. The coastal plains of marginal sea coasts vary in width and may be bordered by hills and low mountains. Rivers entering the sea along marginal sea coasts often develop extensive deltas because of the reduced intensity of wave action associated with small bodies of water. Typical marginal sea coasts border the South and East China Seas, the Sea of Okhotsk, and the Gulf of Mexico.

It is apparent that the morphologic counterparts of (1) collision coasts; (2) trailing-edge coasts; and (3) marginal sea coasts become respectively: (i) narrow-shelf hilly and mountainous coasts; (ii) wide-shelf plains coasts; and (iii) wide-shelf hilly coasts. A complete classification would also include coasts formed by other agents such as glacial scour, ice-push and reef-building organisms, adding two other types of coast: (4) arctic coasts and (5) coral reef coasts.

Paleoclimate and Sealevel Change

Climate, through its control of glaciation, is the principal factor leading to changes in sealevel. The Pleistocene Epoch is characterized by cycles of alternate cold and warm periods producing glacial and interglacial stages.

The last glacial stage known as the Wisconsinan had a maximum about 18,000 years BP. Since that time climate has warmed causing glaciers to melt and sealevel to rise in what is generally known as the Flandrian transgression (Figure 3). Tide gauge records indicate that sealevel is still rising on a worldwide (eustatic) basis at a rate of about 15 cm per century (Barnett, 1984; National Research Council, 1987), and there is the distinct possibility of an increased rate of rise due to the greenhouse effect of carbon dioxide released by man in coming years (e.g., Emery, 1980). This continuing rise in sealevel increases sea cliff erosion and produces a gradual retreat of beaches and barrier islands on a worldwide scale. If all of the ice on earth were to melt it would raise sealevel about 78 meters above present level (Barry, 1981).

Sealevel curves for deglaciated areas show a net emergence due to the "glacial rebound" associated with the removal of the ice load (Figure 4). Viscoelastic models (e.g., Peltier, 1986) show that uplift occurs in the areas of greatest ice loading, and that a draw-down (subsidence) can occur in areas marginal to the area of loading. This may explain why portions of the mid-Atlantic coast of the United States show relative sealevel rise of about 30 cm/century; one-half of this may be due to eustatic sealevel rise while the remainder is viscoelastic draw-down (Figure 4).

The present relatively long, near still-stand in sealevel has produced coastlines that are unique for the Holocene and probably for the entire Pleistocene Epoch. The sealevel has been relatively high during the past three to six thousand years, accentuating the broad shelves carved into the continental platform during this and previous high stands. As a consequence, stream valleys cut at lower sealevel are filling, streams near the coast are "at grade," and coastlines typically have long continuous beaches of sand.

COASTAL PROCESSES

Similarities and differences in coastal types are most easily understood in terms of

nearshore circulation cells and the budget of sediment in *littoral cells*. Nearshore circulation cells determine the path of wave-driven water circulation on a local scale of about 1 km on ocean beaches, while the budget of sediment concerns the sources, transport paths and sinks of sediment in a littoral cell of coastal length 10 km to 100 km.

Nearshore Circulation

The interaction of surface waves moving towards the beach with other, trapped waves traveling along the shore produce alternate zones of high and low waves that determine the position of seaward flowing rip currents. The rip currents are the seaward return flow for the longshore currents that flow parallel to the shore inside of the surf zone. The pattern that results from this flow takes the form of a horizontal eddy or cell, called the nearshore circulation cell (Figure 5). Nearshore circulation cells are ubiquitous wherever waves break along sandy beaches, and the intense, concentrated, seaward flow of their rip currents is the principal cause of drowning for inexperienced swimmers.

The nearshore circulation system produces a continuous interchange between the waters of the surf zone and the shelf, acting as a distributing mechanism for nutrients and as a dispersing mechanism for land runoff. Offshore water is transported into the surf zone by breaking waves and particulate matter is filtered out on the sands of the beach face. Runoff from land and pollutants introduced into the surf zone are carried along the shore and mixed with the offshore waters by the seaward flowing rip currents.

Two important mixing mechanisms are operative within the surf zone, each having distinctive length and time scales determined by the intensity of the waves and the dimensions of the surf zone. The first is associated with the breaking wave and its bore, which produce rapid mixing in an on-offshore direction. This mixing gives coefficients of eddy diffusivity of the order of $H_b X_b / T$ where H_b and T are the breaker height and period of the waves and X_b is the width of the surf zone. The second process is advective and is associated with the longshore and rip current systems in the nearshore circulation cell. This longshore mixing mechanism gives an apparent eddy-mixing coefficient of the order of $Y v_l$ where v_l is the longshore current velocity and Y is the longshore spacing between rip currents. Along ocean beaches $H_b X_b / T$ and $Y v_l$ are about $10 \text{ m}^2/\text{s}$ and $100 \text{ m}^2/\text{s}$ respectively (Inman et al 1971).

In addition, coastal circulation cells of large dimension are associated with the submarine canyons that cut across the shallow shelves of the world (Inman, et al., 1976). The submarine canyons act as deep, narrow conduits connecting the shallow waters of the shelf with deeper water offshore. At times strong seaward flows of water occur in the canyons, resembling large scale rip currents. The canyon currents produce circulation cells having the dimensions of the shelf width and the spacing between the submarine canyons. These strong currents in submarine canyons seem to be caused by a unique combination of air-sea-land interactions consisting of: (i) a "pile-up" of water along the shoreline caused by strong onshore winds; (ii) down-canyon pulses of water caused by the alternate high and low grouping (surf beat) of the incident waves; (iii) a shelf seiche excited by the waves and by the pressure fluctuations in the wind field; and finally, (iv) the formation of continuous down-canyon currents as the accumulated weight of the sediment dislodged by the currents overcomes the density stratification of the deeper water.

Littoral Cells and the Budget of Sediment

A basic approach to understanding the relative importance of nearshore processes is to compare the sea's potential to erode the land, with the land's potential to supply terrestrial erosion products. Such a comparison ultimately resolves itself into the balance between the budget of power in waves and currents and the budget of sediments available for transport. Of course, this balance varies widely from place to place and, even in the best studied areas, is but poorly understood. However, order of magnitude estimates can be attempted by considering the types of driving forces and the resulting sediment response in terms of the budget of sediment.

Waves move sand on, off, and along the shore. Once an equilibrium beach profile is established, the principal transport is along the coast. Theory and measurements show that the longshore transport rate of sand is proportional to the longshore stress-flux of the waves.¹

The budget of sediment for a region is obtained by assessing the sedimentary contributions and losses to the region and their relation to the various sediment sources and

¹The longshore stress-flux is CS_{yx} where C is the phase velocity of the nearbreaking waves and S_{yx} is the longshore radiation stress (e.g. Inman and Brush, 1973; Inman and Dolan, 1989, equations 6.2, 6.3).

transport mechanisms. Determination of the budget of sediment is not a simple matter, since it requires knowledge of the rates of erosion and deposition as well as understanding of the capacity of various transport agents. Studies of the budget of sediment show that coastal areas can be divided into a series of discrete sedimentation compartments called "littoral cells". Each cell contains a complete cycle of littoral transportation and sedimentation including sources and sinks of sediment, and transport paths. Littoral cells take a variety of forms, but there are two basic types. One is characteristic of collision coasts with submarine canyons, while the other is more typical of trailing-edge coasts where rivers empty into large estuaries as shown in Figure 6 (e.g., Inman and Brush, 1973; Inman and Dolan, 1989).

COASTAL ZONE SIMILARITIES AND DIFFERENCES

Mixing and longshore transport of nutrients, pollutants and sediment occurs in the nearshore circulation cells that are ubiquitous to all coastal zones. However the dimensions and intensities of mixing and sediment transport are determined principally by wave climate. Higher waves produce wider surf zones and more intense mixing and transport. In general, windward coasts like the Pacific coast of the United States are subject to more consistent wave action with seasonal variations in intensity between summer and winter. In contrast, leeward coasts like the mid-Atlantic coast of the United States tend to have lower levels of average wave intensity, but episodic interruptions by occasional severe tropical storms in summer and extratropical "northeasters" in winter (e.g. Inman and Dolan, 1989, p. 218). This results in more consistent mixing and transport process on windward coasts and more episodic processes on leeward coasts.

The elements in the budget of sediment may be significantly different between the coastal types. These differences are associated with the steepness of the continental shelf and with the proximity of coastal mountains and streams that debouch directly into the sea. For example, rivers and streams are generally important sediment sources for collision coasts whereas cliffs, shelf and barrier roll-over are generally more important sources along trailing edge coasts.

Collision Coasts

Collision coasts are erosional features characterized by narrow shelves and beaches backed by wave-cut seacliffs. Along these coasts with their precipitous shelves and submarine canyons, as in California, the principal sources of sediment for each littoral cell were the rivers, which

periodically supplied large quantities of sandy material to the coast. The sand is transported along the coast by waves and currents until the "river of sand" is intercepted by a submarine canyon, which diverts and channels the flow of sand into the adjacent submarine basins and depressions (Figure 6a).

In the San Diego region of California most coastal rivers have dams that trap and retain their sand supply. Studies show that in this area the yield of sediment from small streams and coastal bluffs has become a significant new source of sediment. It was also found that the cluster-storms associated with the 1982/83 El Niño-Southern Oscillation phenomena produced beach disequilibrium which resulted in downwelling currents that carried sand onto the shelf (Inman and Masters, 1991). Normal wave action contains sand against the coast and, when sediment sources are available, results in accretion of the shorezone. High total-energy wave events cause a loss of sand from the shorezone via downwelling currents that deposit sand on the shelf. The downwelled sediment is lost to the shorezone when deposited on a steep shelf such as that off Oceanside, California (Figure 6a), or it may be returned gradually from a more gently sloping shelf to the shorezone by wave action.

In all cases where measurements were made just before and after the 1982/83 cluster storm events, and the profiles were distant from structures, it was found that these storm events resulted in the lowest level of beach sand in the history of the observations. Using the profiles north of Oceanside Harbor where conditions are closest to natural and unaffected by harbor effects, it was found that the 38 km of the central Oceanside subcell during 1982/83 lost an unprecedented 33 million cubic meters of sand from the shorezone in one year! Such a volume represents perhaps a 50-year supply of sediment to the shorezone under normal conditions (Inman and Masters 1991).

California beaches are narrow and backed by eroding seacliffs that in many places have buildings on their brink. Since a wide beach is the best protection for eroding seacliffs, a major problem for these coasts is finding adequate sources of sand for beach nourishment.

Trailing-Edge and Marginal Seas Coasts

The mid-Atlantic coast of the United States with its characteristic wide shelf bordered by coastal plains is a typical trailing-edge coast. This low-lying barrier island coast has large estuaries occupying drowned river valleys. River sand is trapped in the estuaries and cannot

reach the open coast. For these coasts, the sediment source is from beach erosion and shelf sediments deposited at a lower stand of the sea, whereas the sinks are sand deposits that tend to close and fill the estuaries (Figure 6b). Under the influence of rise in relative sealevel, the barriers are actively migrating landward in a roll-over process in which the volume of beach face erosion is balanced by rates of overwash and fill from migrating inlets (e.g. Leatherman, 1981; Inman and Dolan, 1989).

The Outer Banks of North Carolina which include the Hatteras and Ocracoke Littoral Cells, extend for 320 kilometers and are the largest barrier island chain in the world. The Outer Banks are barrier islands separating Pamlico, Albemarle and Currituck Sounds from the Atlantic Ocean. These barriers are transgressing landward, with average rates of shoreline recession of 1.4 m/yr between False Cape and Cape Hatteras. Oregon Inlet, 63 km north of Cape Hatteras, is the only opening in the nearly 200 km between Cape Henry and Cape Hatteras which bounds the Hatteras Littoral Cell. Oregon Inlet is migrating south at an average rate of 23 m/yr and landward at a rate of 5 m/yr. The net southerly longshore transport of sand in the vicinity of Oregon Inlet is between one-half and one million m³/yr.

Averaged over the 160 km from False Cape to Cape Hatteras, sealevel rise accounts for 21% of the measured shoreline recession of 1.4 m/yr. Analysis of the budget of sediment indicates that the remaining erosion of 1.1 m/yr is apportioned between overwash processes (39%), longshore transport out of the cell (22%), windblown sand transport (18%), inlet deposits (10%), and removal by dredging at Oregon Inlet (11%). This analysis indicates that the barrier system moves as a whole, so that the sediment balance is relative to the moving shoreline (Lagrangian grid). Application of a continuity model to the budget suggests that, in places such as the linear shoals off False Cape, the barrier system is supplied with sand from the shelf.

Marginal sea coasts are characterized by more limited fetch and a reduced wave energy. Accordingly, river deltas are more important sources of sediment than along the mid-Atlantic coast. Otherwise, barrier island roll-over processes are quite similar. Along both coasts offshore mining of sand may become important sources of beach nourishment.

Arctic Coasts

Tectonically, Arctic coasts are of the stable, trailing-edge type, with wide shelves backed by broad coastal plains built from fluvial and glacial deposits. Tidal amplitudes are small, and

both ice and water motion are controlled predominantly by the wind. The Coriolis effect of east and west blowing winds result in water level increases and decreases in excess of 1 meter.

At 70 degrees north latitude, the sun does not rise for 7 weeks in winter and does not set for over 10 weeks in summer. During the nine months of winter, the coast is frozen fast so that coastal processes are entirely cryogenic and dominated by ice-push phenomena. Wind stress and ocean currents buckle and fracture the frozen pack ice into extensive grounded, nearshore, pressure ridge systems known as stamukhi zones. The keels from the individual pressure ridges groove and rake the bottom plowing sediment towards the outer barrier islands. During the three months of summer, the ice pack withdraws from the Beaufort Sea coast forming a 25 to 50 km wide coastal waterway.

In contrast to winter, the summer processes are classical nearshore phenomena driven by waves and currents as shown by the beaches and barrier island chain in the vicinity of Prudhoe Bay (Figure 7). The sediment sources include river deltas, onshore ice-push across the shelf, and thaw-erosion of the low-lying permafrost seaciffs. Thaw-erosion rates of the shoreline are typically 5-10 m/yr in arctic Russia and, over a 30 year period, averaged 7.5 m/yr for a 23 km coastal segment of Alaska's Beaufort Sea coast (Reimnitz and Kempema, 1987).

The Flaxman Barrier Island chain extends westward from the delta of the Canning River. It appears to be composed of sand and gravel from the river, supplemented by ice-push sediments from the shelf (Figure 7). The prevailing easterly waves move sediment westward from one barrier island to the next. The channels between islands are maintained by setdown and setup currents associated with the Coriolis effect on the wind-driven coastal currents.

Coral Reef Coasts

These coasts result from the biogenic activity of the fringing reefs which in turn depend on special latitudinal conditions. The configuration of the reef platforms themselves incorporates the nearshore circulation cell into a unique littoral cell (Figure 8). The circulation of water and sediment is onshore over the reef and through the reef channels and offshore out the awa's. The awa's are equivalent to the rip channels on the sandy beaches of other coasts (Inman et al, 1963).

In the unique situation of coral reef coasts, the corals, foraminifera, and calcareous algae are the sources of sediment. The overall health of the reef community determines the supply of beach material. Critical growth factors are light, ambient temperature, and nutrients. Turbidity

and excessive nutrients are deleterious to the primary producers of carbonate sediments. On a healthy reef, grazing reef fishes bioerode the coral and calcareous algae and contribute sand to the transport pathway onto the beach.

The beach acts as a capacitor storing sediment transported onshore by the reef-moderated wave climate. It buffers the shoreline from storm waves, and releases sediment to the awa's. In turn, the awa's channel runoff and turbidity away from the reef flats and out into deep water. Where the reef is damaged by excessive terrigenous runoff, waste disposal, or overfishing, the beaches are imperiled.

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FIGURE CAPTIONS

Figure 1. Schematic illustration of the formation of a collision coast and a trailing-edge coast. Representative of section from the East Pacific Rise (spreading center) through the Peru-Chile trench off South America at 35° South Latitude (from Inman and Nordstrom, 1971).

Figure 2. Definition sketch for coastal zone nomenclature. The type of coast is related to its relative position on the moving plates of the tectosphere; wide-shelf plains coasts (a) and narrow-shelf mountainous coasts (b) are characteristic of the east coast (trailing-edge) and west coast (collision edge) of the Americas, respectively (after Inman and Brush, 1973).

Figure 3. Late Quaternary fluctuations in sealevel. Solid line is the "generalized" sealevel curve (from Curray, 1965); dashed line is detailed curve (from Curray, 1960, 1961). Tree ring and Uranium/Thorium dates give greater age than the radiocarbon ages for these curves. Recent studies indicate the glacial maximum was 21,000 ($^{230}\text{Th} / ^{234}\text{U}$) years BP with a sealevel lowering of 121 ± 5 m (400 ± 16 ft) (Fairbanks, 1989; Bard et al., 1990).

Figure 4. The predicted rate of uplift(+) and subsidence (-) in cm/century resulting from Laurentide deglaciation according to the viscoelastic model of Peltier (1986).

Figure 5. Schematic diagram of nearshore circulation cell consisting of onshore transport by the breaking wave, longshore transport in the surf zone and offshore transport by seaward flowing rip currents. Floating and suspended material is deposited on the beach face by (a) wave runup and by (b) water percolating through the beach sand (after Inman et al., 1971).

Figure 6. Sediment source, transport paths and sinks for typical littoral cells along (a) collision and (b) trailing-edge coasts. Arrows show sediment transport paths; dotted arrows indicate occasional on and offshore transport modes.

Figure 7. Flaxman Barrier Littoral Cell extending from Brownlow Point off the Canning River to Reindeer Island, Alaska. Sediment sources, transport paths, and mechanisms are shown schematically. Hachured areas defined by the 18-foot depth contour.

Figure 8. Schematic diagram of littoral cells along a fringing reef coast (after Kapaa Reef, Inman et al., 1963).

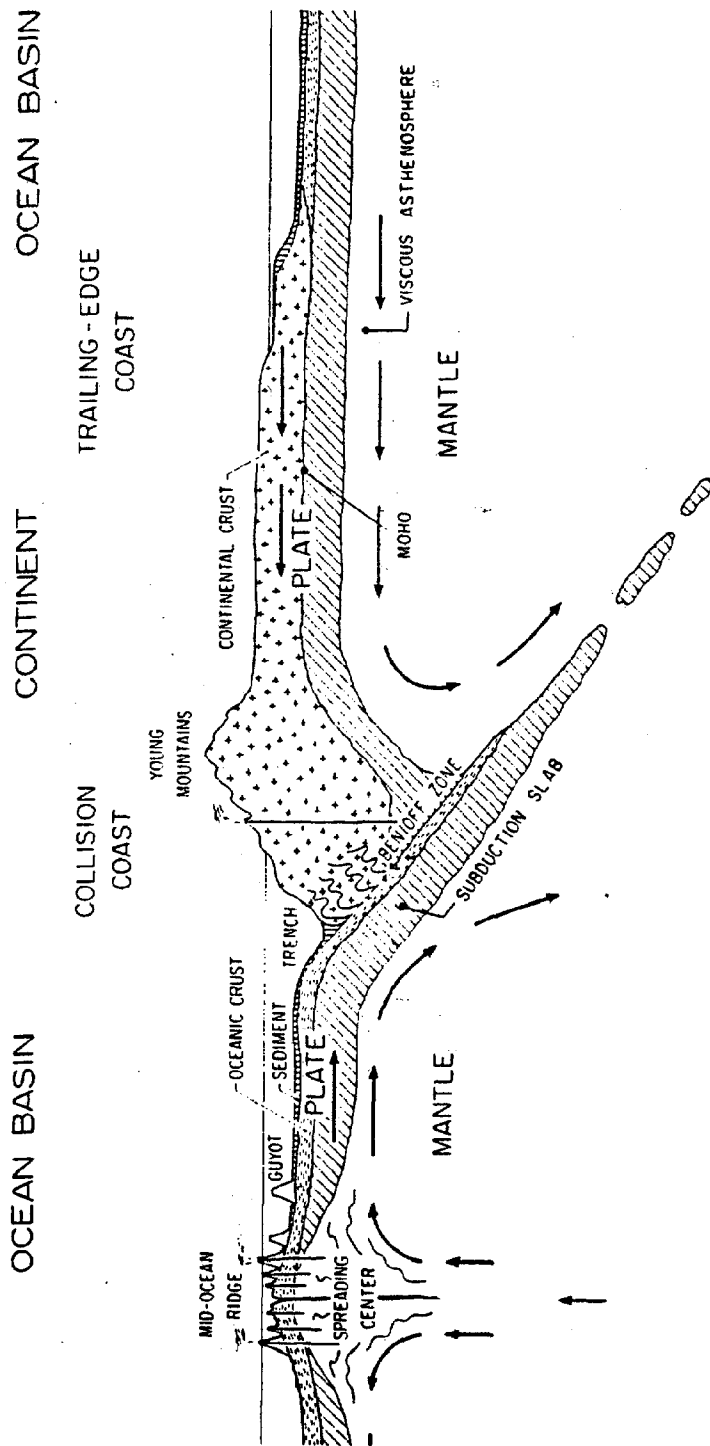


Figure 1

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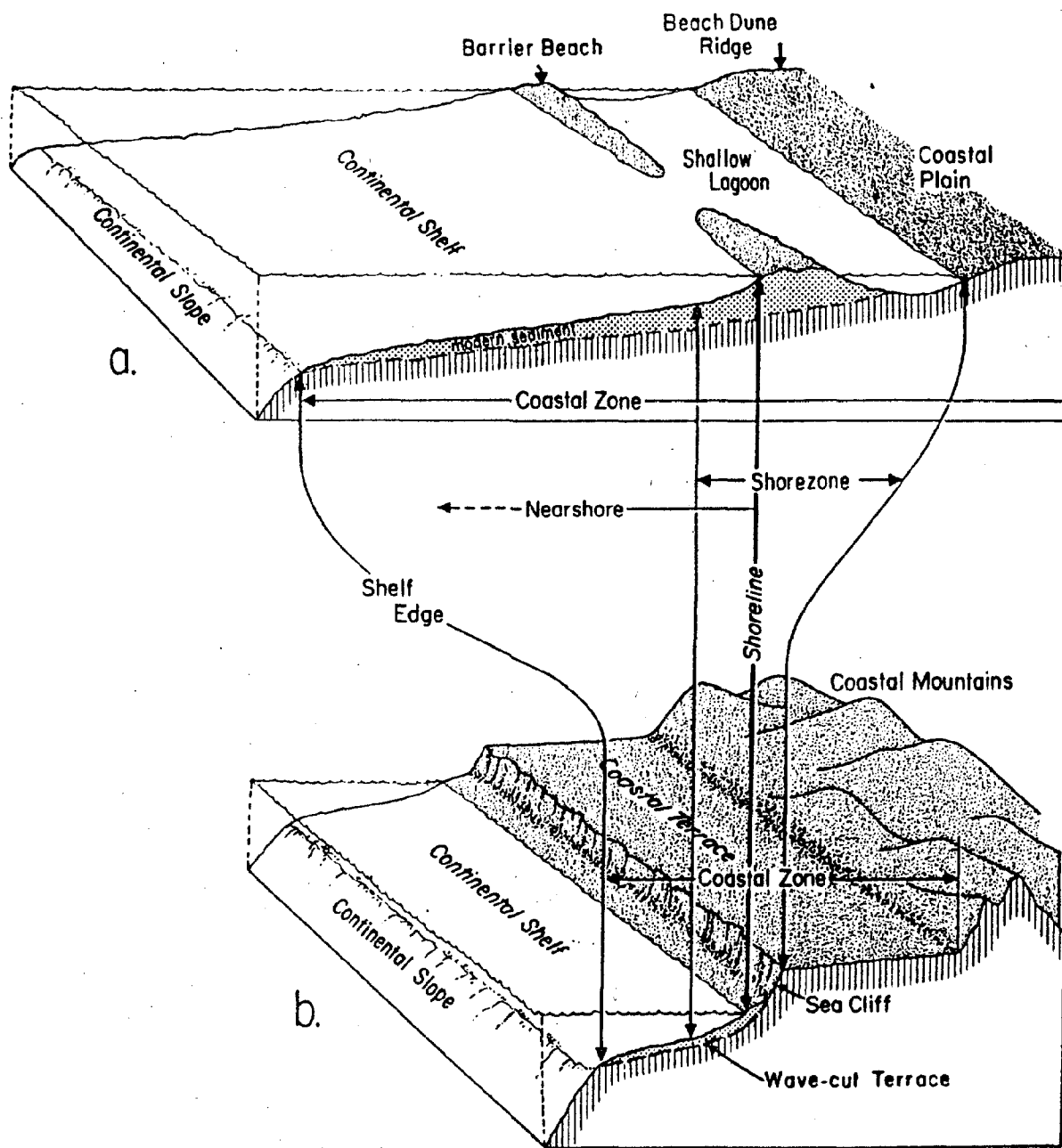


Figure 2

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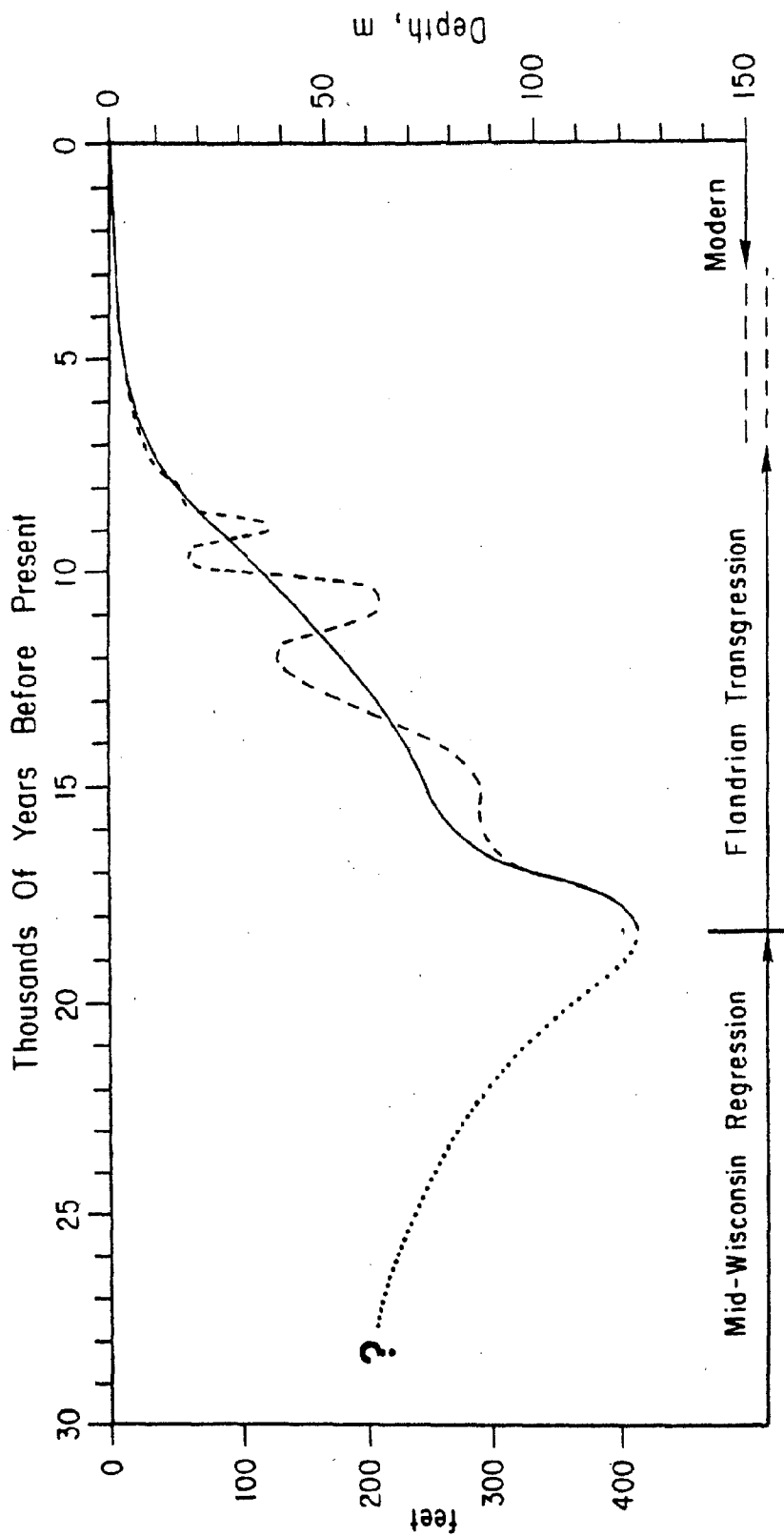


Figure 3

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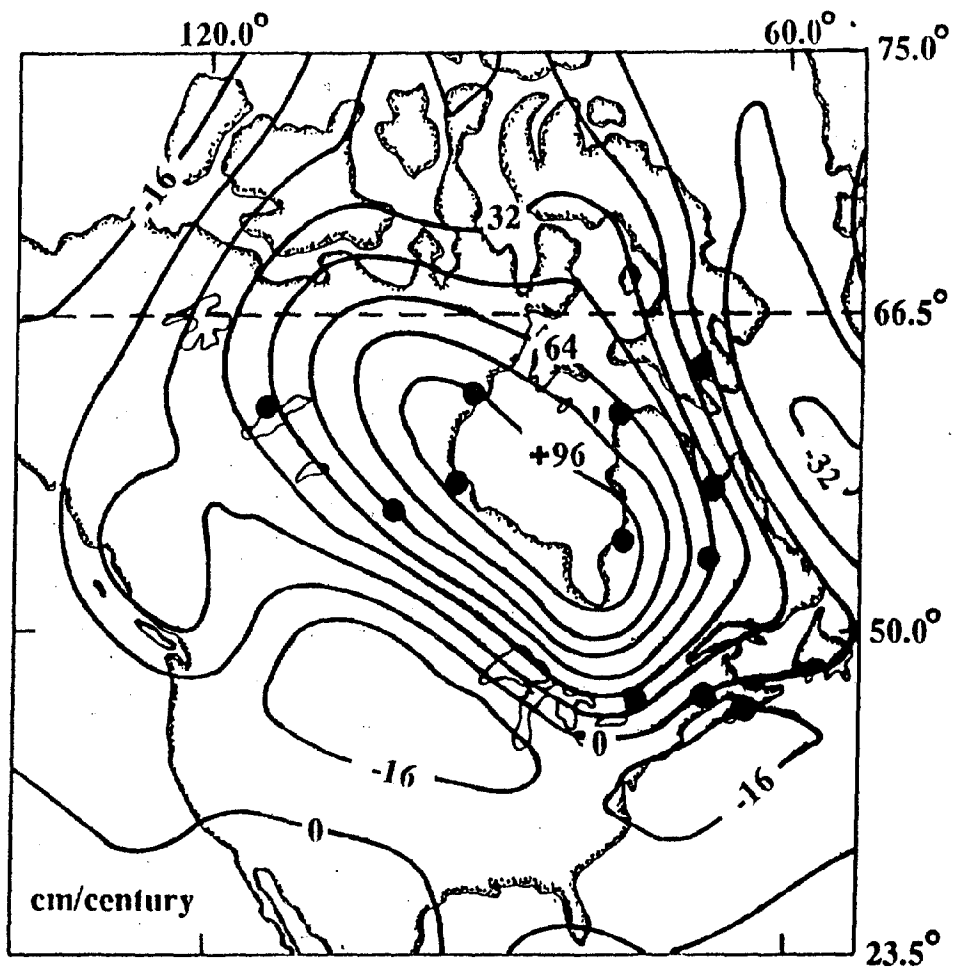


Figure 4

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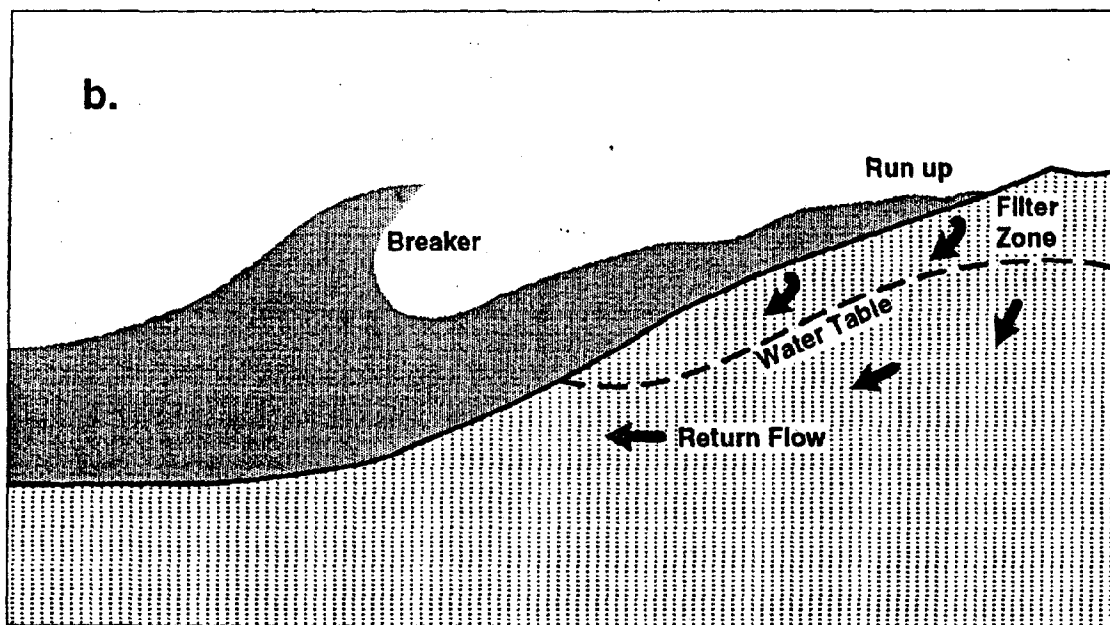
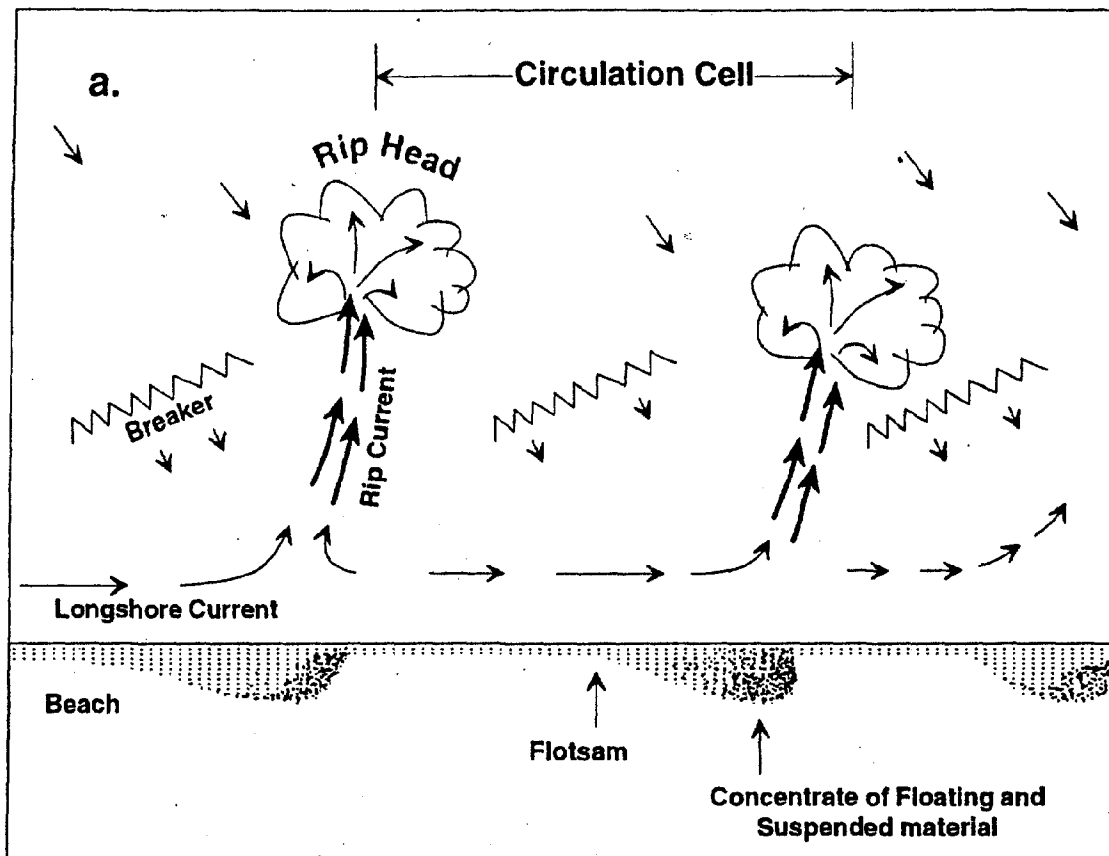
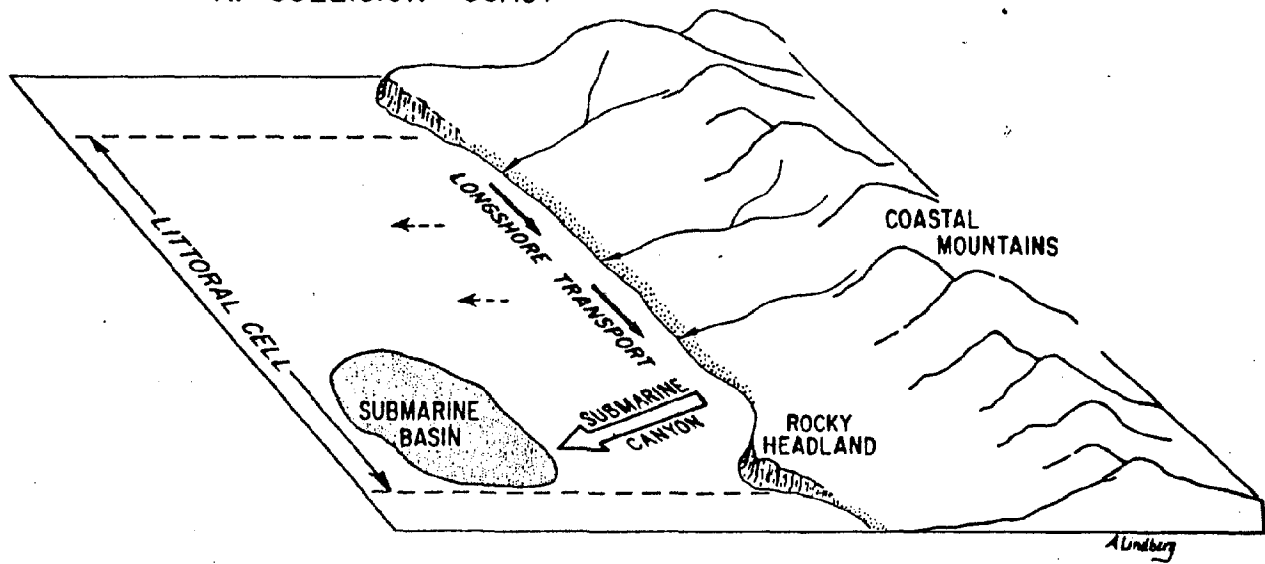


Figure 5

D.L.I.

A. COLLISION COAST



B. TRAILING-EDGE COAST

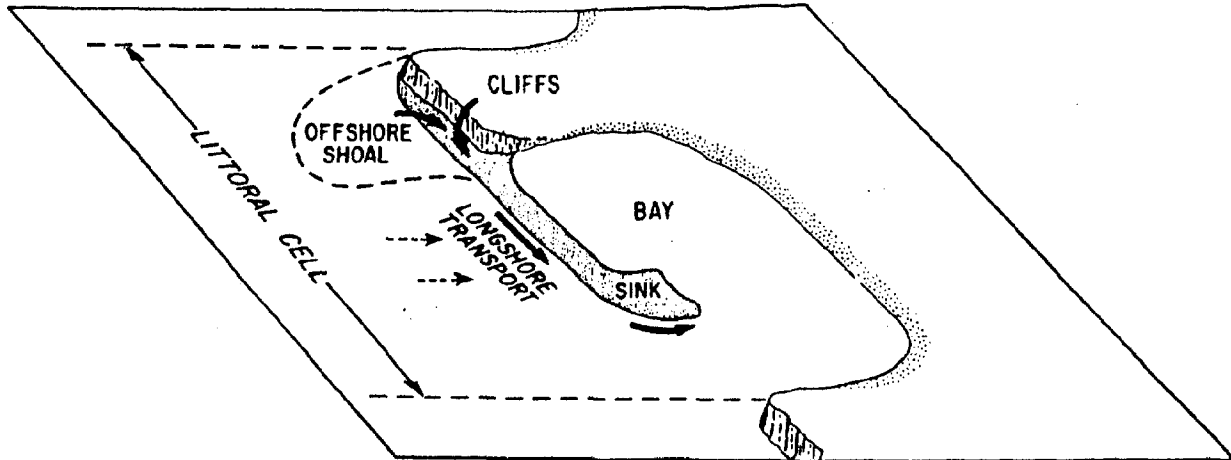


Figure 6

D.C.I.

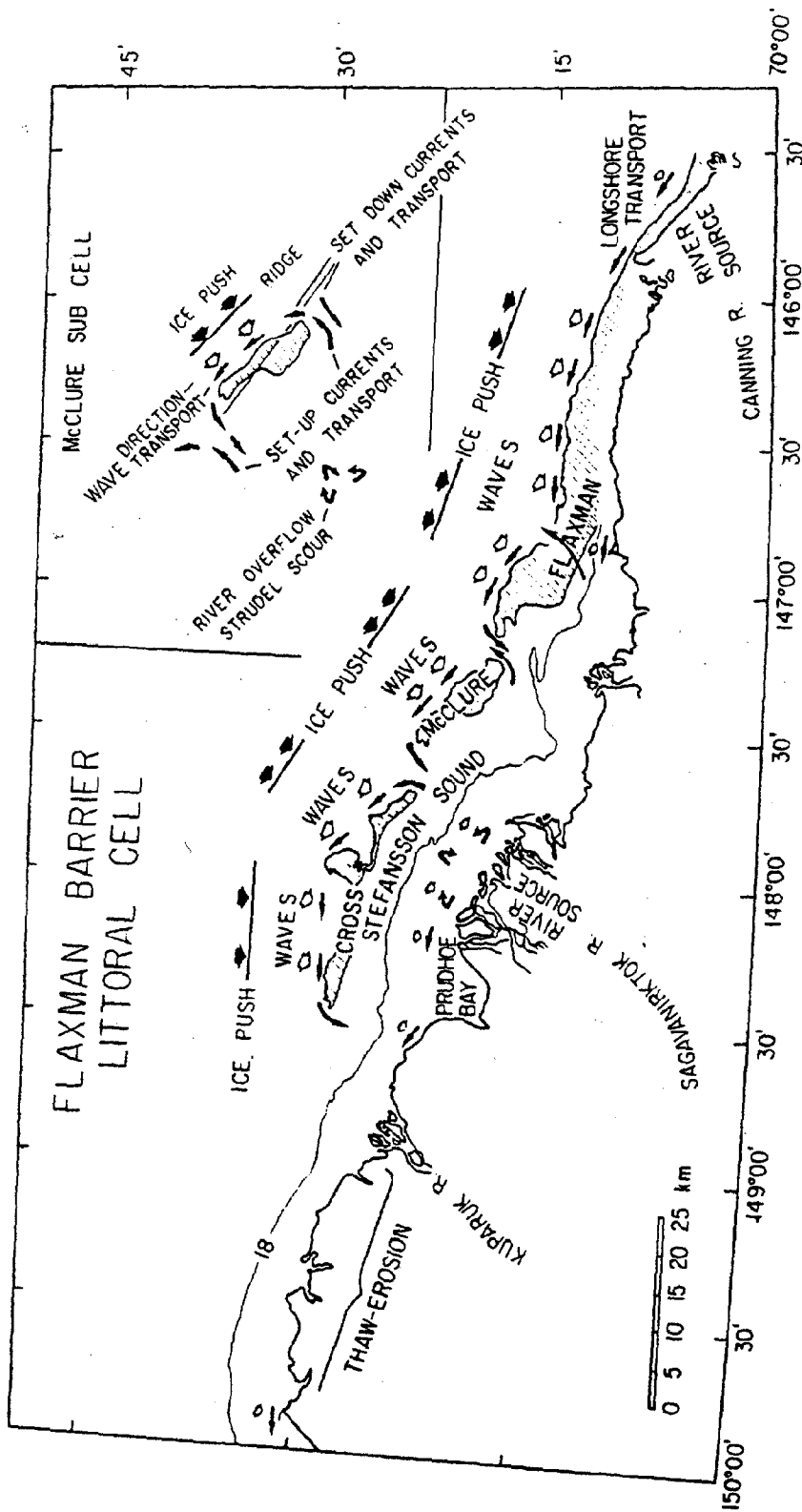


Figure 7

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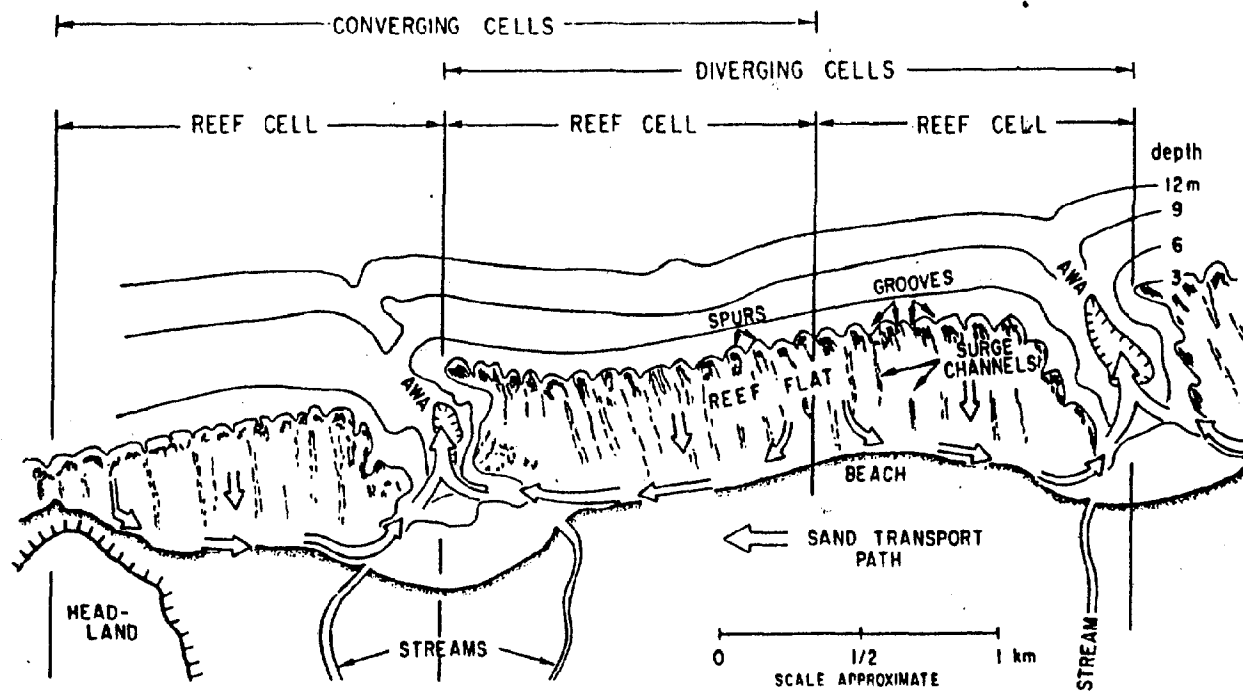


Figure 8

D.I.

Coastal Wetlands: Multiple Management Problems In Southern California

by

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San Diego State University

for the June 1992 CGER Retreat on

"Multiple Uses of the Coastal Zone in a Changing World"

Introduction

California's 1973 Coastal Act was one of the nation's earliest attempts to plan for the coexistence of multiple coastal users. However, lack of support from recent governors, budget cuts, and intense population pressure have eroded California's status as a leader in coastal zone management. Multiple uses are now resulting in multiple conflicts (Table 1), and estuarine wetlands are particularly threatened. The federal government has shown little interest in California estuaries. In fact, only two have been included in EPA's National Estuary Program: San Francisco Bay, and Santa Monica Bay, and only 4 of the 19 National Estuarine Research Reserves are on the Pacific Coast; of these Elkhorn Slough and Tijuana Estuary are in California. The limited interest in Pacific Coast wetlands extends to research support as well. It has been suggested that management models can be based on East Coast research and relationships and then modified to fit the West Coast (Sutherland 1991). This idea needs to be questioned.

Southern California estuaries have several unique qualities. The estuaries are small and isolated. The variability of various environmental factors (annual rainfall, timing of rainfall, storm intensity, and streamflow) is very high. Catastrophic events have lasting impacts on coastal wetlands. For example, Mugu Lagoon (near Santa Barbara) recently lost 40% of its low-tide volume due to flood-deposited sediments (Onuf and Quammen 1983). Periodic El Niño events raise sea levels and increase storm frequencies. Coastal dunes are sometimes washed into the estuaries, especially where stabilizing vegetation has been denuded. At Tijuana Estuary, the shoreline has retreated 300 ft since 1852, with major erosion during the 1983 El Niño storms (Williams and Swanson 1987).

Hydrologic features are also unusual. Freshwater discharge greatly influences the accumulation of sand from long-shore sediment transport processes in southern California. Estuarine inlets have a tendency to close, and the size of the tidal prism determines their ability to stay open to tidal flushing. Where watersheds are highly modified (disturbed soils and vegetation), erosion and sediment inflows can greatly reduce tidal prisms. Increased freshwater inflows cause native salt marsh vegetation to be replaced by brackish invaders (Zedler and Beare 1986).

Finally, southern California has lost most of its coastal wetland habitat. In California as a whole, 91% of the wetland area (coastal + inland) has been converted to other uses; this is the nation's highest loss rate (Dahl 1990). On the coast, only about a fourth of the historic acreage is left, and much of it is in San Francisco Bay. Most of the ~26 wetlands in southern California have some protection as habitat reserves. However, all have been reduced in size and are disturbed to various degrees. In the San Diego area, salt marshes have declined drastically. The acreage of tidal salt marsh in Tijuana Estuary, San Diego Bay and Mission Bay is only 13% of its historic area (San Diego Unified Port District 1990). With all these habitat losses and damages, biodiversity is at risk. The State of California recognizes 10 coastal animal species as endangered or threatened with extinction (Dept. of Fish and Game 1989). The California Native Plant Society considers 17 coastal wetland plants as rare.

This paper discusses two problems in southern California, both of which have aspects that are unique to the region. The first concerns wastewater management. Because municipal water supplies are imported from well outside the region, the release of treated effluent to streams threatens the hydrologic regime of coastal rivers and downstream estuaries. The second problem is mitigation. The region lacks the sites that are needed for mitigation projects, and there are no proven methods for replacing habitats used by endangered species. The paper ends with a consideration of the adequacy of the research base for dealing with these issues.

The Wastewater Issue

The 100+ estuaries along California's 1100-mile-long coast receive streamflows in pulses, due to the region's Mediterranean-type climate with winter rainfall and summer drought. Under natural conditions, it

is likely that streams had minimal flow in summer. In the San Diego region, dams reduce winter streamflows and wastewater discharges increase summer streamflows to coastal estuaries. Filling to build roads across the estuaries has reduced tidal prisms and increased chances of inlet closure. In general, the impact of development has been to decrease tidal influence and increase freshwater inflow, both by increasing the volume of fresh water discharged to the coastal wetlands and by prolonging the period of streamflow.

This region continues to grow very rapidly; more 85,000 people moved to San Diego in 1987, and growth rates were just as high in 1988 and 1989. Development is moving inland, and it is becoming more expensive to discharge wastes to ocean outfalls. It has been proposed that the wastewater be treated and discharged to coastal streams for reuse in irrigation downstream during the dry season. The California Regional Water Quality Control Board (San Diego Region WQCB 1988) projects discharges of 10-30 million gallons per day of treated wastewater for 10 coastal rivers over the next 25 years. It is uncertain how much of the flow would reach coastal wetlands, but certainly during the wet season, the wastewater discharge would exceed irrigation demands.

It is now recognized that changing the hydrology from intermittent to continuous flows will affect coastal water bodies and endangered species habitat. The coastal wetlands are usually saline to hypersaline ecosystems. A concern that is peculiar to semi-arid regions is salinity dilution, which occurs when intermittent streams that normally provide seasonal freshwater to coastal lagoons become year-round rivers due to wastewater discharge.

Some effects of dry-season flows to coastal wetlands have been documented. We know that prolonged periods of freshwater influence can force the replacement of salt marsh habitat (which is endangered species habitat) to brackish marsh (which is not) (Zedler and Beare 1986, Beare and Zedler 1987). Continuous freshwater flows also eliminate the marine invertebrates and shellfishes that are native to many coastal lagoons. At Tijuana Estuary, the numbers of fish and macroinvertebrate species have been reduced substantially since 1986; numbers of individuals have dropped by an order of magnitude; and size distributions are markedly altered--for clams, only young-of-the-year can be found, indicating that larvae are available to settle in the estuary, but rarely survive to reproductive age (Nordby and Zedler 1991). Experimental tests of the effect of salinity dilution on fish and invertebrates have demonstrated that low

salinity causes mortality, especially of molluscs (Nordby, Zedler, and Baczkowski, unpub. data). Detailed experimentation with California halibut shows that growth of juveniles is impaired by lowered salinity and that impacts are greatest on the smallest and youngest individuals (Baczkowski 1992). Thus, modifications to the seasonality of streamflow (i.e., the semi-arid hydrology) of the region are seen as significant impacts, beyond the more general problems of nutrients and toxic materials that are carried in wastewater.

Decision makers are aware of the negative impacts of year-round inflows, and plans are underway to recover much of the treated effluent downstream for use in irrigation. There would still be spills and excess water during the wet season. Unfortunately, the impacts of excess freshwater discharge, of greater volumes of freshwater inflow, and of increased nutrient loadings to coastal water bodies are only generally predictable.

Raw sewage from Tijuana: The City of Tijuana includes large urban areas that are not on sewer, and wastes are discharged as raw sewage to Tijuana River. About 13 million gallons per day were released to Tijuana River and Tijuana Estuary between about 1986 and 1991 (Seamans 1988, Zedler et al. 1992). As in other regions, wastewater inflows carry unwanted materials into estuaries. What is unique in this case is the high concentration of pollutants, both because of lower per capita water use (concentrated wastewater) and fewer controls on contaminant loadings (industrial discharges).

The nitrogen and phosphorus that enter the Tijuana Estuary are of largely of wastewater origin. Mexican sewage contains over 25 mg/l nitrogen and greater than 10 mg/l phosphorus. We have shown that Tijuana Estuary is nitrogen limited, and that macroalgal blooms are stimulated by wastewater inflows (Fong et al., 1987). Studies of heavy metals in Tijuana Estuary showed that surface water samples contain mean levels of 69 ppb cadmium, 55 ppb chromium, 281 ppb nickel, and 321 ppb lead (Gersberg et al. 1989). The lead level is relatively high. The sediments of the estuary, which may act as a sink for heavy metals, contained up to 1.7 ppm cadmium, 25 ppm chromium, 14 ppm nickel, and 59 ppb lead. Hot spots of contamination do exist in the estuary.

Short-term solutions and long-term plans have been developed. In fall 1991 the raw sewage was diverted to a holding lake in the US, held briefly and then pumped to San Diego's sewage treatment plant

during off hours. However, the pumps were shut down during rain storms in winter 1992 and failed for one week in May 1992. The short-term solution is a band-aid approach.

A long battle has been waged over who would pay for wastewater treatment at the border. The City of San Diego did not want to pay for treatment of "international waste." But the City did want a treatment plant that would serve new developments on the US side. The federal government, in turn, did not want to pay for local infrastructures. The compromise was to build two sewage plants, a 25 MGD plant to handle Mexico's sewage and a much larger plant to be built by the City of San Diego to treat local wastewater. To handle the effluent from both plants, a 12-foot-diameter outfall is being constructed to carry up to 300 MGD of wastewater to the ocean. This outfall would cross Tijuana Estuary and damage a 200-foot-wide swath of endangered species habitat during construction. Mitigation is proposed. An alternative tunnel is being planned; the outfall pipe could go under Tijuana Estuary at greater construction cost. It is not clear that the estuarine biota could sustain the damages of either construction project, even with mitigation efforts.

Management and policy needs. The region faces dwindling water supplies and burgeoning effluent. The need for long-term solutions is obvious. Year-round reuse of water would obviate the need for a destructive ocean outfall. Year-round reuse would also solve problems both at the source (San Francisco Bay Delta, where freshwater inflows are needed to sustain the biota of the Bay) and at the disposal site. The drinking of wastewater that is produced and treated in California is permitted only if it has passed through a groundwater aquifer. The concern is apparently the potential for transmission of viruses. Further research on the safety and acceptability of total recycling is needed.

Second, treated wastewater could be used to construct wetlands. Freshwater wetlands could subsidize habitat for estuarine birds; at the same time, they would improve water quality entering the estuaries. In San Diego County, freshwater bulrush (*Scirpus validus*) wetlands have a particularly high capability for nitrogen removal, with greater than 90% reduction of total nitrogen at 5-6-day hydraulic residence times (Gersberg et al. 1986). Constructed wetlands are also capable of removing both bacterial and viral indicators of pollution with a removal efficiency of nearly 99.9% for poliovirus (vaccine strain; Gersberg et al. 1987).

Since augmented inflows are detrimental to the region's estuaries, these constructed wetlands could be engineered to discharge treated wastewater in pulses that would minimize negative impacts (i.e., salinity dilution) on the downstream estuary. Recent experimentation with pulsed-discharge regimes (alternating impoundment and discharge) demonstrated that both metal and nitrogen removal rates could be increased by twice-daily impoundment and discharge (Sinicrope et al. in press, Busnardo et al. in press). Several additional benefits might also occur. More nitrogen would be removed through enhanced denitrification; more metals would be immobilized through precipitation in the sediment; there might be fewer problems with mosquitoes due to the more dynamic hydrology. It appears that the problem of augmented freshwater inflows could be lessened (although not eliminated) by using pulsed-discharge wetlands to reduce the impact of salinity dilution and improve the quality of effluent entering the coastal wetlands. The potential for using constructed wetlands to manage wastewater in southern California needs to be explored.

The Mitigation Issue

The principal value of southern California's coastal wetlands is habitat and its role in maintaining biodiversity. Several species are dependent on our estuaries (including plants and animals, invertebrates and vertebrates, and both resident and migrant species). Three endangered birds and one plant species depend on coastal wetlands that cover less than 25% of their historic area and that are far from pristine. Despite laws that protect wetlands and endangered species, regulatory agencies still permit habitat alterations if mitigation plans promise compensation. Lost habitat is usually "replaced" by restoring disturbed wetlands, with a net loss of wetland acreage and often a decline in habitat quality (Zedler 1991).

The National Environmental Policy Act [40 CFR Part 1508.20(a-e)] defines mitigation as avoiding, minimizing, rectifying, reducing, eliminating or compensating for impacts to natural resources. Wetland filling is regulated by the Clean Water Act, Section 404, which requires a permit for filling of or disposing dredge spoil into wetlands. Filling is allowed for water-dependent uses (e.g., port facilities), and where there is "no practicable alternative," providing that impacts are mitigated. Wetland mitigation usually involves restoration or enhancement of disturbed wetlands. Rarely does it involve construction of new wetland habitats from

nonwetlands. Whether restoration, enhancement, and construction measures can preserve coastal diversity remains a major question.

Mitigation projects in progress. The Ports of Los Angeles and Long Beach propose to fill 2400-2500 acres of nearshore habitat by the year 2020 to expand port facilities. Several mitigation projects have been proposed, and at least one (at Anaheim Bay/Seal Beach National Wildlife Refuge) has been implemented. A second (374 acres of dredging at Batiquitos Lagoon) has reached the Final EIR/EIS stage. Environmentalists believe the dredging is excessive and that it suits the Ports' needs for mitigating fish habitat more than the lagoon's need for enhancement. The project is currently in litigation.

Some projects are not water-dependent, but permits are still possible in southern California. A current proposal by the City of San Diego is to relocate and expand an existing sewer pump station within an intertidal salt marsh. The specific site was recently shown to support the largest population of an annual plant (*Lasthenia glabrata*) that is considered sensitive. Mitigation would be proposed. However, the native distribution, population dynamics, habitat requirements and reproductive characteristics of this rare plant have not been studied.

Highways are usually not permitted in wetlands, but most of southern California's coastal wetlands are interrupted by three roadways (Interstate Hwy 5, Pacific Coast Highway, and the Santa Fe Railroad). There are continual plans to widen these roadways, with associated impacts on the remaining wetland resources. Along San Diego Bay, the salt marsh was recently damaged by three federal projects: the widening of a freeway, a new freeway interchange, and a new flood control channel. The US Fish and Wildlife Service determined that three endangered species were jeopardized by the projects, and compensatory mitigation was required (see next section).

The basic problems with mitigation in southern California are that 1) there isn't enough coastal acreage to satisfy the demand for mitigation projects; 2) too much wetland habitat has already been lost and several species are threatened with extinction; 3) even the most disturbed wetlands provide some support for threatened species, so that changing a degraded habitat into a mitigation site causes further negative impacts; and 4) we don't understand how these degraded wetlands function. In addition to these problems, the research that has been done to assess the functional equivalency of restored and natural wetlands

indicates that we do not yet know how to recreate endangered species habitats. To date, the process of mitigation has been an attempt to offset losses, but the policy breaks down at several levels, including planning, site selection, and project implementation.

An attempt to compensate for lost endangered species habitat: The San Diego Bay mitigation was a habitat conversion. Disturbed high marsh/transition was converted to low marsh for a federally endangered bird (the light-footed clapper rail). Prior to excavation, the mitigation site may have supported the Belding's Savannah sparrow, a bird on the state endangered list. No biological inventory was required or conducted to document existing values of the mitigation site.

Research is continuing to assess the functional equivalency of restored and natural wetlands of San Diego Bay. In 1985, 8 salt marsh islands were constructed as habitat for an endangered bird. Over a two-year period (1987-89), eleven attributes of the mitigation site were compared with those at an adjacent natural marsh. There were deficiencies in soils (Langis et al. 1991), plant growth (Zedler, in press), and marsh invertebrates (Rutherford 1989). Sampling of soils and vegetation continued through 1992, and improvements were minimal, giving little evidence that the site will eventually support the target species, the light-footed clapper rail.

Compared to reference marshes, the sediment was sandier and had little organic matter. With less soil organic matter, there was less energy and nitrogen for microbial mineralization and less energy for nitrogen fixation. With lower nitrogen inputs, plant growth was limited and foliar nitrogen was lower. With lower plant production and lower quality plant biomass, the detrital food chain was probably impaired, as indicated by lower abundances of invertebrates in the epibenthos. Five years after construction, the best sites (areas with highest plant cover) provided less than 60% of the functional value of the natural reference wetland (Zedler and Langis 1991). More recent research shows that canopy architecture (cordgrass height and density) differed for the planted marshes (which do not support clapper rails) and natural marshes. Tall plants are needed to support nesting and provide protection from aerial predators. Transplanted marshes have few plants over 60 cm, while most stems in natural marshes exceed 60 cm (Zedler, in press). This appears to be a major reason why the marsh islands are not yet used by the light-footed clapper rail.

It should be possible to accelerate development of these ecosystem processes, using scientific knowledge and experimentation at existing mitigation projects. Current policies are not sufficient to protect against extinction. Research is underway to find soil amendments and enrichment schedules that will produce taller, denser cordgrass in a shorter period of time. Preliminary experiments with straw, alfalfa and inorganic nitrogen fertilizers show that nitrogen addition can improve plant growth (Gibson 1992). However, after 2 years, the canopy architecture is not yet equivalent to that of natural marshes. Continued research and repeated applications seem to be necessary.

Management policies and issues. It has not yet been shown that damages to endangered species habitat can be reversed or that lost wetland values can be replaced. Replacement of functional values is slow and incomplete. Yet, policies have not been changed to reflect the inadequacy of mitigation projects. Permits are still being granted with the promise that habitat can be replaced. Several federal policies are not appropriate for the southern California situation.

- **Mitigation priorities.** Federal mitigation policy (EPA and COE Memorandum of Agreement) recommends that restoration be given priority over the creation of new wetlands from upland. This policy makes sense in some places, such as prairie potholes that are drained and farmed and no longer function as wetlands. Restoration of former potholes is more likely to provide the correct hydrology than excavation of potholes from natural upland. However, where damaged wetlands still perform critical functions, as in southern California, this strategy is doubly damaging--first, the restoration site is altered without knowing what existing values were lost; second, there is a net loss in wetland area.

- **Mitigation ratios and "net loss of acreage and function."** The recommendation that mitigators restore 2-4 times the area they damage is a good idea. However, it is not sufficient where endangered species habitats are concerned. Since even the disturbed wetlands have valued functions, the use of a 2:1 mitigation ratio (i.e., restoration of 2 acres of marsh for every 1 acre lost) does not fulfill the policy of no net loss of wetland area. Instead, there is a net loss of 1 acre of wetland area. Only the creation of wetland from non-wetland areas can replace lost wetland acreage. Lower functional value of restored or created wetlands does not compensate for lost endangered species habitat. Even if 3:1 or 4:1 compensation is required, a larger area of unusable habitat will not replace the functional value of one acre that is critical to the

endangered population. At the very least, agencies should require assessment of the functioning of the mitigation site prior to and after improvements, plus "up-front" mitigation, with "success" achieved and documented prior to destruction of the development site.

- **Sediment removal:** Most restoration projects in southern California involve excavation of sediments that have accumulated from coastal watersheds or former fills. However, sediments may ultimately be needed to offset sea level rise. Most agencies lack policies that require consideration of accelerated rates of sea level rise in their long-term planning.

- **Dredge spoil disposal.** Off-site disposal of fine sediments is extremely costly and may be environmentally damaging to the disposal site. A proposed solution for disposal of fine sediments at Batiquitos Lagoon is to bury them in situ, but excavating the underlying sand and using it for beach replenishment. However, this would extend the time period of the disruption of biota of Batiquitos Lagoon, and temporary stockpiles of spoils would affect nearby coastal areas. Regional plans for sediment disposal are needed, with an emphasis on finding beneficial uses of the material (e.g., capping toxic waste deposits).

- **Research policies:** NOAA's Coastal Ocean Program proposes to develop a conceptual model of estuarine habitat function based on East Coast models (Costanza et al. 1990). The objective is to "relate the location and extent of seagrass and salt marsh habitats to the production of living marine resources in an estuary or region" (Sutherland 1991). Although this program has provided some support for the soil amendment experiment in San Diego Bay, most of the funding has been for research in East and Gulf Coast habitats. The applicability of production models to southern California management issues concerning endangered species habitats is questionable. Research funding agencies need to recognize the unique attributes of Pacific Coast ecosystems and to reevaluate the geographic distribution of their funding efforts.

The Status of Research on Coastal Southern California Ecosystems

In November 1991, the California State Sea Grant Program sponsored a workshop on "Research Needs for Restoring Sustainable Coastal Ecosystems on the Pacific Coast" at the Estuarine Research Federation (ERF) meetings in San Francisco (Williams and Zedler 1992). The consensus was that ecosystem research on Pacific estuaries lags behind that on Atlantic and Gulf Coast estuaries by several

decades. Even basic data on California estuarine wetlands (size, type, historic condition) are unavailable. Little is known of the habitat requirements of Pacific estuarine species, including plants, fishes and wildlife. For plant species that have been studied, such as *Salicornia virginica* and *Spartina foliosa*, we still do not have data on belowground dynamics. For these and other unstudied species, we lack data on dispersal mechanisms, reproductive strategies, and genetic structure. Estuarine food webs have not been elucidated and feeding relationships have not been quantified. The research needs are numerous, as indicated by attendees at the recent national workshop (Table 2).

Conclusion

The uniqueness of Pacific coastal wetlands requires a regional approach to research and management. Whereas the nutrient content of freshwater entering East and Gulf Coast estuaries needs to be controlled, in southern California the amount and timing of discharges must also be managed in order to maintain native vegetation and associated fauna. It is not sufficient for managers to worry only about the loss of fish and shellfish habitat, because endangered species are often jeopardized by wetland loss in southern California. Management models cannot be derived by extrapolation from data of East and Gulf Coast estuaries, where inflows are more predictable and where plants and animals are more tolerant of brackish water.

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Table 1. Major Uses of the Southern California Coast and

Ports: The Ports of Los Angeles and Long Beach occupy San Pedro Bay. To expand their role as the major Pacific Rim shipping center, they propose to fill ~2400 more acres of shallow subtidal habitat by the year 2020.

Problems: Nearshore fish habitat will be filled. Mitigation to compensate for lost habitat is mandated, but there are no nearby sites where compensatory habitat restoration or construction can occur, because all the historic sites have been filled and urbanized.

Marinas: Many former wetlands have marinas. There is constant pressure to increase the number of boat slips for San Diego's growing population and its substantial tourism industry. America's Cup generated further expansion.

Problem: Marina development impacts eelgrass beds and associated fisheries (e.g., California halibut). No studies have documented the functional value of natural eelgrass beds or of mitigation sites where eelgrass has been transplanted. Since so much eelgrass habitat has been destroyed, and since eelgrass is a clonal species, transplanted eelgrass beds may lack genetic diversity.

Urbanization: Most of the coast above mean high water is urbanized. Were it not for a military base (Camp Pendleton), the 120-mile coast between Los Angeles and San Diego would be one continuous urban strip. The San Diego Region now has 2.5 million people, with approximately 2 million more in adjacent Tijuana, Baja California. The growth rate is variable for the San Diego area, but newcomers averaged 85,000 per year from 1987-89.

Problems: There is no buffer zone between urban areas and coastal habitats. Urban run-off degrades coastal water bodies; noise, lights and human activities occur immediately adjacent to endangered species habitats. There is constant pressure to "use" wildlife preserves.

Military bases: San Diego grew up around the Naval Base on San Diego Bay. There is also a Marine Corps Recruit Training Depot on San Diego Bay and a Marine Base (Camp Pendleton) in northern San Diego County. There are military airfields at Tijuana Estuary (helicopters) and Miramar Naval Air field (jets), which is just north of San Diego.

Problem: It is not known whether coastal military bases are releasing contaminants. Contaminants from anti-fouling paints (e.g., tributyltin, copper) are known to be a problem at the Navy harbor.

Problem: San Diego Bay must be dredged to maintain ship channels.

Problem: Helicopters practice about 950 take-offs and landings per day, with flights directly over the Tijuana River National Estuarine Research Reserve.

Airports: Tijuana, San Diego, Long Beach, Los Angeles, and Santa Barbara all have commercial airports. San Diego's airport is entirely surrounded by high-cost housing, commercial, and military land uses. Various alternatives are under consideration for major expansion.

Problems: Expansion in situ would encroach on the Marine Corps Recruit Depot and increase noise levels for nearby residents. Relocation to Miramar Naval Airfield would interfere with military activities. Locating a new airport adjacent to the international border (adjacent to Tijuana's airport) would increase flights over Tijuana and have planes taking off and landing over a National Estuarine Research Reserve. All U.S. users of the airport live north of the latter site; travel to and from the airport would be maximized, with most people having to drive through San Diego to reach the airport.

Agriculture: Minimal agricultural efforts are carried out along the coast; however, there are agricultural activities in the Tijuana River Valley, several areas of floriculture inland of coastal lagoons, and vegetable farming on the marine terrace at Camp Pendleton.

Problem: Non-point source pollutants and irrigation runoff flow into coastal wetlands. Algal blooms and fish kills are possible impacts.

Recreation: Sandy beaches offer many recreational opportunities. Mission Bay Park is billed as the "world's largest urban water-recreation park" (1,888 acres). Formerly shallow subtidal and wetland habitat, the park was constructed by dredging embayments and building islands. The area now supports water skiing, jet skiing, sailing, rowing, canoeing, kayaking, swimming, sunbathing, and passive nature appreciation. At Tijuana Estuary, horse trails are heavily used by equestrian clubs and rental operations.

Problems: Incompatible uses are crowded into small areas. Noisy boats and jet skiers have negative impacts on those seeking quiet. Accidents occur--in Mission Bay, jet skiers and boaters collide; at Tijuana Estuary, hikers get kicked by horses. It is not easy to eliminate incompatible users. A model airplane club that was located within the Tijuana River National Estuarine Research Reserve was ruled as incompatible, when planes repeatedly crashed at an experimental research site. But, it took over 5 years and considerable expense to evict them, even though their lease had expired.

Research and Education: These activities take place at several habitat remnants along the coast. Visitor Centers occur at Tijuana Estuary, San Diego Bay, and at some of the north County lagoons. Tijuana Estuary is a research reserve, but it is managed by the California Department of Parks and Recreation, which does not have a research mandate.

Problem: Intensive use is damaging to native habitats and species; yet trails are desired for interpretive purposes. Most habitats are used by sensitive species, so there is no good place for interpretive or recreational facilities. Blinds are often suggested, but homeless people and undocumented migrants on their way north are attracted to such structures.

International Border: Every day, hundreds of undocumented immigrants cross the border at Tijuana, Mexico. The traffic flows on many undesignated paths, many of which cross through or near endangered species habitat, such as the beach areas where California least terns nest.

Problems: Many of the immigrants walk, wade, and swim through Tijuana Estuary. They damage the habitat, as does the Border Patrol force, whose job it is to pursue and arrest them. Nests of endangered birds are damaged.

Gravel and sand extraction: Coastal rivers have been mined for both sand and gravel. These materials are highly valued in a region undergoing rapid development. An extraction company has developed an ambitious proposal to remove the surface 180 feet of the highlands at the US-Mexico Border, to sell the sand and crush the cobbles to make gravel.

Problem: These highlands are an important buffer between Tijuana River Valley and the metropolis along the Mexico border. Eliminating these bluffs would have serious impacts on the integrity of the National Estuarine Research Reserve. The long-term extraction period (>10 years) would disrupt endangered species habitat throughout the valley. It is estimated that there would be more than 1 truck per minute transporting sand or gravel, plus the construction and operation of a rock crusher.

Coastal reserves: Coastal wetlands comprise a small but important acreage along the coast, since they support many species that are threatened with extinction. Several sites have been set aside for various conservation purposes. Tijuana Estuary is a National Estuarine Research Reserve; it includes a State Park and a National Wildlife Refuge for endangered species. At San Diego Bay, the Sweetwater Marsh is a National Wildlife Refuge. At Mission Bay, the Kendall-Frost Reserve is owned by the University of California and is set aside for research. North of San Diego, there are several coastal lagoons that are ecological reserves; the Calif. Department of Parks and Recreation owns Los Peñasquitos Lagoon; the County of San Diego owns San Elijo Lagoon, and the California Dept. of Fish and Game owns Buena Vista Lagoon. Private holdings include large parts of Agua Hedionda Lagoon (San Diego Gas & Electric) and Ballona Wetland near the Los Angeles Airport (~250 acres, Maguire Thomas Partners).

Problem: No single agency manages the region's wetlands. Yet migratory birds and mobile fishes and invertebrates are often the management target. Several species that are unique to the region are threatened with extinction. Tijuana Estuary supports 24 sensitive plant and animal species, yet the management of these populations is not easily coordinated within the region.

Problem: California's 91% loss of historic wetland area indicates that further extinctions will occur. E. O. Wilson's island biogeography model predicts that 50% of the species will be lost when 90% of the habitat is eliminated.

Problem: It is extremely costly to purchase wetland remnants for the public. The Famosa Slough was recently purchased by the City of San Diego (20 acres for \$3.5 million) for a nature reserve and for public interpretation. This site had a development plan but it would probably not have received a Section 404 permit. Near Santa Barbara, public agencies paid over \$340,000 per acre to acquire a 4-acre parcel adjacent to Carpinteria Marsh for purposes of restoration. This filled site was developable land.

Problem: Proposed changes in the wetland delineation guidelines would seriously impair habitat conservation efforts. The higher elevations of coastal marshes support rare and endangered plants (the salt marsh bird's beak) and insects (mudflat tiger beetles). With increased rates of sea level rise, the upper marsh and transition habitats must be available for the landward migration. EPA calculates that a half meter rise by the year 2100 is probable--this would eliminate 65% (6,441 square miles) of the wetlands of the contiguous US.

Problem: Restoration plans are designed to meet the needs of mitigators, rather than what may be most functional at the site or most needed in the region. No program has been developed to assess the quality of each habitat type in the region, to assess losses by habitat type, or to determine the habitat needs of the region. Almost all mitigation planning is done on a piecemeal basis.

Problem: Much of the wetland area that remains in the region is publicly owned, but no single agency owns all the reserves. Management is accomplished on a site-by-site basis.

Table 2. RESEARCH PRIORITIES FOR SUSTAINABLE PACIFIC ESTUARIES
(from Williams and Zedler 1992)

This list is divided into four subject areas of equal importance: conservation of biodiversity, physical processes, water quality, and restoration. The categories were ranked by workshop participants with (1) designating a higher and (3) a lower priority. The tally below represents the mean ranking by fifteen respondents.

Conservation of Biodiversity Research Needs

- 1.27 Habitat function determinants
 - structural (marsh edge, canopy height)
 - functional (productivity, trophic support)
- 1.30 Habitat requirements/habitat specificity of organisms
 - primary determinants of habitat utilization (trophic/reproduction requirements)
 - structure (e.g., habitat heterogeneity, canopy height)
 - function (e.g., productivity)
- 1.42 Population dynamics
 - genetic structure & diversity
 - minimum viable population sizes
 - community development processes (rates, rate-limiting processes)
 - belowground vegetation processes
- 1.89 Linkages between communities & habitats
- 1.90 Trophic dynamics
 - food web analysis
 - emergent insect communities
- 2.02 Exotic species biology
 - dispersal mechanisms
 - competitive effects
 - trophic effects
- 2.09 Habitat inventory
 - determination of estuarine acreage and habitat types
 - 'community-profiles' on sites with long-term database
- 2.10 Endangered species biology
- 2.65 Effects of rare events

Physical Processes Research Needs

- 1.23 Hydrology
 - effects of altered hydrology
 - effects of vegetation
 - effects of marsh morphology (channel vs. overmarsh flow)
 - effects of alternating wet-dry cycles
 - models
- 1.78 Erosion/accretion responses
 - role of organic vs. inorganic matter in accretion
 - integration with hydrological effects
 - sediment supply processes
- 1.97 Model of salinity dynamics (modal & extreme)
- 2.22 Effects of anticipated sea level rise
- 2.36 Marsh morphology
 - role of extreme events
 - comparisons between marsh types

Water Quality Research Needs

- 1.51 Nutrient dynamics
 - process rates
 - budgets
 - organic matter accumulation & decomposition rates
 - effects of alternating wet-dry cycles
 - effects of altered hydrology
- 1.53 Criteria for vegetation
- 1.71 Urban runoff
- 1.81 Impacts of development
- 1.90 Treatment strategies

Restoration Research Needs

- 1.17 Inventory of projects and monitoring
- 1.29 Habitat architecture
 - habitat size to sustain minimum viable population sizes & functionality
 - habitat heterogeneity
 - landscape linkages & corridors
 - buffer zone requirements
- 1.59 Site selection criteria
 - identification of potential sites
 - consideration of regional habitat biodiversity
 - urban problems
- 1.65 Monitoring & evaluation of success
 - assessment & standardization of functionality evaluation criteria
 - assessment of appropriate temporal scales of monitoring
 - assessment criteria for urban projects where no natural sites remain for comparison
 - assessment of structure (e.g., canopy height) as surrogates for function
- 1.94 Methodology
 - identification of desired initial conditions
 - establishment of desired initial conditions
 - independent tests of design strategies
 - acceleration of functional development trajectory
 - incorporation of effects of rare/stochastic events in design
- 2.48 Economic evaluation of adequacy of mitigation/restoration options as compensation for loss

Background Paper:

Workshop on "Multiple Uses of the Coastal Zone in a Changing World".

Landscapes and the Coastal Zone

by

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"Each shade of blue or green sums up in itself a structure and a history, for each lake is a small world, making its nature known to the larger world of the desert most clearly in its colour. These little worlds of turquoise, set among red, brown, grey and white rocks, are not independent of the dry landscape around them.In the quality of this scene, accentuated by the foetid sulphurous water that lies at the bottom of the lake, may be traced the whole life of the surrounding country" (G. E. Hutchinson, *The Clear Mirror* 1936)

Introduction

Scientists, and particularly managers, often look at the coastal zone without referring to the larger landscape in a quantitative way. A conspicuous management practice illustrating the dichotomy between the landscape scale of examination and management action involves permit decisions. The typical Federal Section 404 permit is evaluated and issued one permit at a time, without serious consideration of the cumulative effects of many permit decisions, thus thwarting the apparent intent of several Federal and State resource management legal instruments (e.g. Bedford and Preston 1988, Gosselink et al. 1990). The influence of landscapes and landscape-scale changes may originate either in situ or far from the immediate area of concern and in often unappreciated ways. The theory of island biogeography (MacArthur and Wilson 1967) is one example of a fruitful quantitative analysis of how the size, relationship and shape of landscape patches affect species distribution. Process-orientated landscape studies are, in contrast, rare. It is my purpose here to illustrate various landscape interactions of coastal ecosystems and thereby encourage integrated analysis and management.

Estuarine Variability in the US

The geomorphology of US estuaries varies enormously, and this variability influences estuarine functions. Examples of estuarine variability are in Figure 1. The drainage basin size,

water surface size, freshwater turnover time, and water:marsh ratio varies by several orders of magnitude from the Maine estuaries around the coast to the state of Washington. Estuarine functions are strongly influenced by this variability, which is, of course, overlain with seasonal, annual and daily cycles. For example, as estuarine flushing time decreases, the likelihood of water pollution problems increases. Fisheries are often limited by wetland area through either refuge or food limitations (e.g. Turner 1992, Turner and Boesch 1987, Figure 2). We know from freshwater studies that landscape pattern may influence bird distributions (Figure 3; Brown and Dinsmore 1986). Examples of area:species relationships for coastal communities are less frequently documented than for terrestrial ecosystem, perhaps because of the variability of estuarine flushing. This variability makes data collection and analysis more difficult. However, some of the earliest studies of species colonization and turnover were done on mangrove islands (by D. Simberloff and colleagues) and the principles should be generally applicable to the coastal zone. Habitat diversity does appear to be related to habitat area, for example (Figure 4).

One cannot easily clone landscapes as in the usual scientific experiment. However, when accomplished, the results may be dramatically illustrative (e.g. Schindler 1977, Likens 1992). Comparisons between landscapes units are often fruitful, and modelling has a role. Some the clearest cases of landscape scale influences comes from documenting recent changes and the cause-and-effect conclusions based on strong inferences. Three case studies of landscape changes are briefly discussed below. In one case (Everglades) the influence of variable water flow patterns are discussed. The second case (Mississippi River) illustrates the probable role of changing riverine nutrient flows and consequences to the continental shelf ecosystem. The third example (coastal Louisiana) discusses the indirect impacts of many small dredge and fill permit decisions - an *in situ* change - on wetland losses.

Case History: South Florida Hydrologic Changes

The ecosystems of south Florida are very sensitive to the fluctuations and duration of soil moisture, flooding, and drying cycles. They are also nutrient-poor systems, especially for

phosphorus (e.g. Ornes and Steward 1973). The natural water balance, in turn, is driven by seasonal and longterm rainfall, evaporation, plant transpiration, belowground seepage, land elevation, soil infiltration and natural channel flow. Water movement from Lake Okeechobee (aprox. +5 m msl) southward for 70 miles towards the Miami area (aprox. +2 m msl) is sensitive to the elevation gradients. Water movement eastward was formerly only through the coastal ridges at high water stages. The westward movement is impeded by sandy ridges averaging about +8 m msl on the western border of the Everglades Agricultural Area (south of Lake Okeechobee). High water is a flood problem for the 3 million residents near Miami, and low water is a threat to the water table and freshwater supplies.

Man has been altering this ecosystem for most of this century. The history of Florida's development (see Table 1), particularly south Florida, began with a simple interest to drain the excess water and then to occupy the land for agriculture. It soon became evident that the limitations of excess water were also matched by the problems of water scarcity. What at first was a plan to drain the swamp by the state, became a complex water management scheme involving local, regional, state and national agencies. A diversity of perspectives, priorities and monies accompanies this complexity. It is a difficult area to manage because it includes a National Park, which is a conservation zone with site-specific and exclusive land use regulations. Human enterprises are inherently interested in stable water supplies, whereas the Everglades ecosystem is very responsive, and requires, fluctuating water supplies. These land use changes have led to the loss or destruction of about one-half of the natural Everglades ecosystem through either direct habitat loss or the indirect influences of development. In particular, water movement through and within the naturally-defined ecosystem has been modified through land use, land drainage, and both water diversions and storage (e.g. in 1990 there are more than 1,400 miles of canals, 65 major spillways, and hundreds of water control structures; Figure 5). Compared to the 1900 conditions, plant coverage is vastly reduced or changed (e.g. Steward and Ornes 1973a, b; Hagenbuck et al. 1974), local weather patterns may have been altered, and there is increased coastal saltwater

intrusion, and fire; animal populations dependent on plants and their predators/decomposers have been put at risk (Tables 1 and 2).

Some specific effects of the altered hydrology are: (1) exotic species are now in the Everglades National Park (e.g. Australian pine (*Melaleuca* sp.), Brazilian pepper, hydrilla, water hyacinth, cajuput, walking catfish, pike killifish, and several species of cichlides); (2) soil subsidence and water level declines since 1900 through much of the ecosystem are measured in feet, not inches (Alexander and Crook 1973); (3) agricultural fertilizers leak to downstream ecosystems; (4) fires are more frequent (e.g. Stephens 1969); (5) perhaps a dozen species are endangered or threatened by extinction whose recovery is compromised by the altered hydrologic cycles; (6) significant legal issues arise over the allocation of water resources and the quality of that water; (7) the long-term sustainability of drained agricultural lands is in doubt; (8) saltwater intrusion is a threat to urban water supplies; and, (9) changes in animal populations occur for those species dependent on plants and their predators/decomposers.

Case History: Mississippi River Watershed Nutrient Additions

The Mississippi River watershed is 41% of the area of the contiguous 48 states (Figure 6). In terms of length, discharge and sediment yield, the main river channel is the third, eighth and sixth, respectively, largest river in the world (Milliman and Meade 1983). The river has been shortened by 229 km in an effort to improve navigation and it has a flood control system of earthwork levees, revetments, weirs, and dredged channels for much of its length that has isolated most riverine wetlands from the main channel and left them drier.

Changes in three indicators of water quality were documented by Turner and Rabalais (1991) and are presented here: phosphorus (as total phosphorus), silicon (as silicate), and dissolved inorganic nitrogen (as nitrate). All three are important nutrients for freshwater and marine phytoplankton growth and production. The pervasive relationships between phosphorus and freshwater phytoplankton communities is well-established (e.g., Schindler 1977 1988, Vollenweider and Kerekes 1980). Diatoms, an important food species for freshwater and marine

fish and invertebrates, require silicon to build their tests. Schelske et al. (1983, 1986) proposed that increased phosphorus loading in lakes stimulated diatom production with the subsequent loss of silicon (as diatom tests) when deposited in sediments. Eventually a new steady-state silicate concentration develops in the water column where diatoms are less numerous and their growth is silicon-limited. Nitrogen often acts in concert with phosphorus to regulate phytoplankton communities in freshwater ecosystems, and may often be the dominate nutrient limiting phytoplankton of estuarine and marine communities (e.g., Valiela 1984, D'Elia et al. 1986, Harris 1986).

The mean annual concentration of nitrate in the lower Mississippi River was about the same in 1905-06 and 1933-34 as in the 1950s, but has subsequently doubled (Figure 7). The mean annual concentration of silicate was about the same in 1905-06 as in the 1950s, and then declined by 50%. The concentration of silicate increased from 1985 to 1988, whereas the concentration of nitrate decreased slightly in the same period. Although the concentration of total phosphorus appears to have increased since 1972 (the earliest records we could find), the variations between years are large and the trends, if they exist, are not clear.

The silicate:nitrate atomic ratios in the lower Mississippi River for this century have changed as the concentrations varied. The silicate:nitrate atomic ratio was about 1:4 at the beginning of this century, 1:3 in 1950, and then rose to about 1:4.5 over the next ten years, before plummeting to around 1:1 in the 1980s.

The seasonal patterns in nitrate and silicate concentration also changed. There was no pronounced peak in nitrate concentration earlier this century, whereas there was a spring peak from 1975 to 1985 (Figure 8). A seasonal peak in silicate concentration, in contrast, is no longer evident. There was no marked seasonal variation in total phosphorus for 1975 to 1985.

The likely causal agent of these changes is the widescale and intensive use of nitrogen and phosphorus fertilizers, which reached a plateau in the 1980s. The current consumption of phosphorus fertilizer use in the US is stable, but increasing throughout the world (Figure 9). There is a direct relationship between annual nitrogen fertilizer use and nitrate concentration in the

river (Figure 10). The predicted indirect relationship between phosphorus fertilizer use and silica concentration in the river is also observed, per the implications of the hypotheses of Schelske et al. (1983, 1986).

The combination of changes in nitrate, phosphorus and silicate has almost certainly influenced the coastal marine phytoplankton community (in particular, a decline in diatom abundance), if not led to increased phytoplankton production, especially if the community is nitrogen limited, as many coastal systems are thought to be. It is not clear, however, if larger or more severe hypoxic zones have formed in bottom waters offshore (Rabalais et al. 1991) as a result of these riverine water quality changes. The effect of the probable decline in diatom abundance, a likely source of the organic matter fueling oxygen consumption rates in offshore hypoxic zones, may have been compensated for by increased abundances of other algal types, especially flagellates.

These changes are important to understand, if only because nitrogen is commonly thought to be limiting phytoplankton growth in coastal and oceanic waters (e.g. Harris 1986, Valiela 1984). The abundance of coastal diatoms is influenced by the silicon supplies, whose Si:N atomic ratio is about 1:1 (the Redfield ratio). Diatoms out-compete other algae in a stable and illuminated water column of favorable silicate concentration. When nitrogen increases and silicate decreases, flagellates may increase in abundance (Officer and Ryther 1980) and form undesirable algal blooms. In particular, noxious blooms of flagellates are becoming increasingly common in coastal systems. Zooplankton, important diatom consumers, and a staple of juvenile fish, are thus affected by these nutrient changes in a cascading series of interactions. Furthermore, where eutrophication occurs, hypoxia often follows, presumably as a consequence of increased organic loading. Supportive evidence of this benthic-pelagic coupling is the observations of Cederwall and Elmgren (1980) who demonstrated a rise in macrobenthos around the Baltic islands of Gotland and Oland, which they attributed to eutrophication, a known event (Nehring 1984).

However, not all coastal systems are nitrogen limited (e.g., the Huanghe in China is phosphorus limited; Turner et al. 1990), nor is changing nutrient loading the only factor influencing phytoplankton growth (Skreslet 1986). Marine phytoplankton may also respond in

various ways to nutrient additions introduced gradually or suddenly, with changing flushing rates or salinity, and with cell density (Sakshaug et al. 1983, Sommer 1985, Suttle and Harrison 1986, Turpin and Harrison 1980).

Management of eutrophication on a national scale has not sufficiently integrated freshwater and estuarine systems. The national freshwater policy is to control phosphorus, and is based on the numerous excellent laboratory and field studies of the stimulatory effect of phosphorus on freshwater ecosystems. However, the analysis and management of nitrogen limited coastal systems is becoming more complicated as the eutrophication modifies the transition zone between phosphorus and nitrogen-limited aquatic ecosystems. A national policy in common to both freshwater and coastal systems is sewerage treatment. But, as is shown for the Mississippi River (Turner and Rabalais 1991), the terrestrial system is very leaky, and treatment does not mean a reduction of loading to the estuary via water and precipitation. So a second understated issue, therefore, is that sewerage treatment upstream does not necessarily equate to controlling nutrient loading to downstream estuaries.

A third point is that mitigation of nutrient applications seems a less prudent management policy, compared to an outright reduction in use. The ecosystem is simply too leaky to control all nutrient flows between the application site and estuary.

Case History: Louisiana Coastal Wetland Dredge and Fill

Dredging is a conspicuous human activity affecting Louisiana's coastal wetlands, is principally related to oil and gas recovery efforts, and results in large areas of canals and residual spoil deposits, or 'spoil banks' (80,426 ha, equivalent to 6.8 % of the wetland area in 1978; Turner 1990; Baumann and Turner 1990; Figure 11). The aggregate length of these spoil banks in Louisiana is in the neighborhood of 12,000 miles and to remove all of them would cost about as much as to build three river diversions, that is, about \$500 million.

There are strong and probably partially reversible cause-and-effect relationships between wetland losses and these hydrologic changes. Canals and spoil banks are the most likely cause of

at least 30-59% of Louisiana's coastal wetland losses from 1955 to 1978 (51,582 ha/yr, or 0.85%/yr; Turner and Cahoon 1987). Wetland losses may be due to either direct or indirect impacts of spoil banks and canals. Sixteen percent of these wetland losses resulted from the direct impacts of dredging wetlands into open water and spoil bank; at least 14 - 43% of these wetland losses were the result of the indirect impacts of spoil banks and canals on tidal water movement into and out of the wetlands. About 13% of the direct wetland losses were due to agricultural and urban expansion into wetlands. Indirect impacts result from the: (1) longer wetland drying cycles, even in semi-impounded wetlands, as a consequence of altered water movements into and out of the wetland. The lengthened drying periods promote soil oxidation and subsequent soil shrinkage (Table 2). Flooding events may also lengthen behind spoil banks (Table 2), presumably as a consequence of water being trapped behind the spoil bank once water enters overland during very high tides; (2) lower sedimentation rates behind spoil banks in *any* wetland type, probably because of the reduced frequency and depth of tidal inundation (Figure 12); (3) Increased waterlogging of soils and that then changes soil chemistry. Plants may become stressed to the point where growth reduction or even die-back occurs (e.g. Babcock 1967; King et al. 1982; Wiegert et al. 1983; Mendelsohn et al. 1987). In addition, the spoil banks consolidate the underlying soils. Water movements belowground are thus decreased, both because of the reduced cross-sectional area and the reduced permeability of material beneath the levee.

The combined effects of sediment deprivation, increased wetland drying and lengthened soil flooding result in a hostile soil environment for plants. The death of plants reduces sediment trapping amongst the plant stems and accumulation of plant material at the soil surface and belowground. Small, shallow ponds may form and enlarge due to scouring under even light winds. The practical consequence of these causal mechanisms is a strong direct relationship between wetland losses and canal density on a local and coastwide basis (e.g. Turner and Rao 1990; Figure 13).

Summary

Landscapes are a functioning legacy of many broad influences, including geology, climate, biological evolution, etc. Landscapes are more than reactive parts that can be understood and managed in isolation from each other. The relationship of edge:whole, size, fragmentation, and human use is reflected in the ecological functions of the parts and of the whole. We must learn to live with the fact that humans are changing landscapes in a multitude of ways. The details may appear as a painting by Cezanne viewed with a magnifying glass - the colorful tones and textures of oil or pastels. But the painting quality, the forms, and impressions, are intended to be considered from further away. Both the natural and managed coastal zone parts must be viewed in this context. Individual permits and the individual species are like the small brushstrokes. They are required for the whole picture, but the picture quality does not completely emerge unless there is a broad and encompassing whole view. Coastal zones must be viewed not only from close-up, but from a distance. Most management excludes that landscape view. The consequences of many small decisions tends to be overwhelming, consistent with the acceptance of the fallacy of multiple uses. Landscape fragmentation and loss of functions will result in the absence of that broad view. This is the history of landscapes (e.g. Hoskins 1970). However, as with a Cezanne painting, the brushstrokes can be changed and managed, one by one, to result in a more masterly painting, and probably will be most likely accomplished with less arrogance about our abilities to substitute intense manipulation for the multitude of natural interactions.

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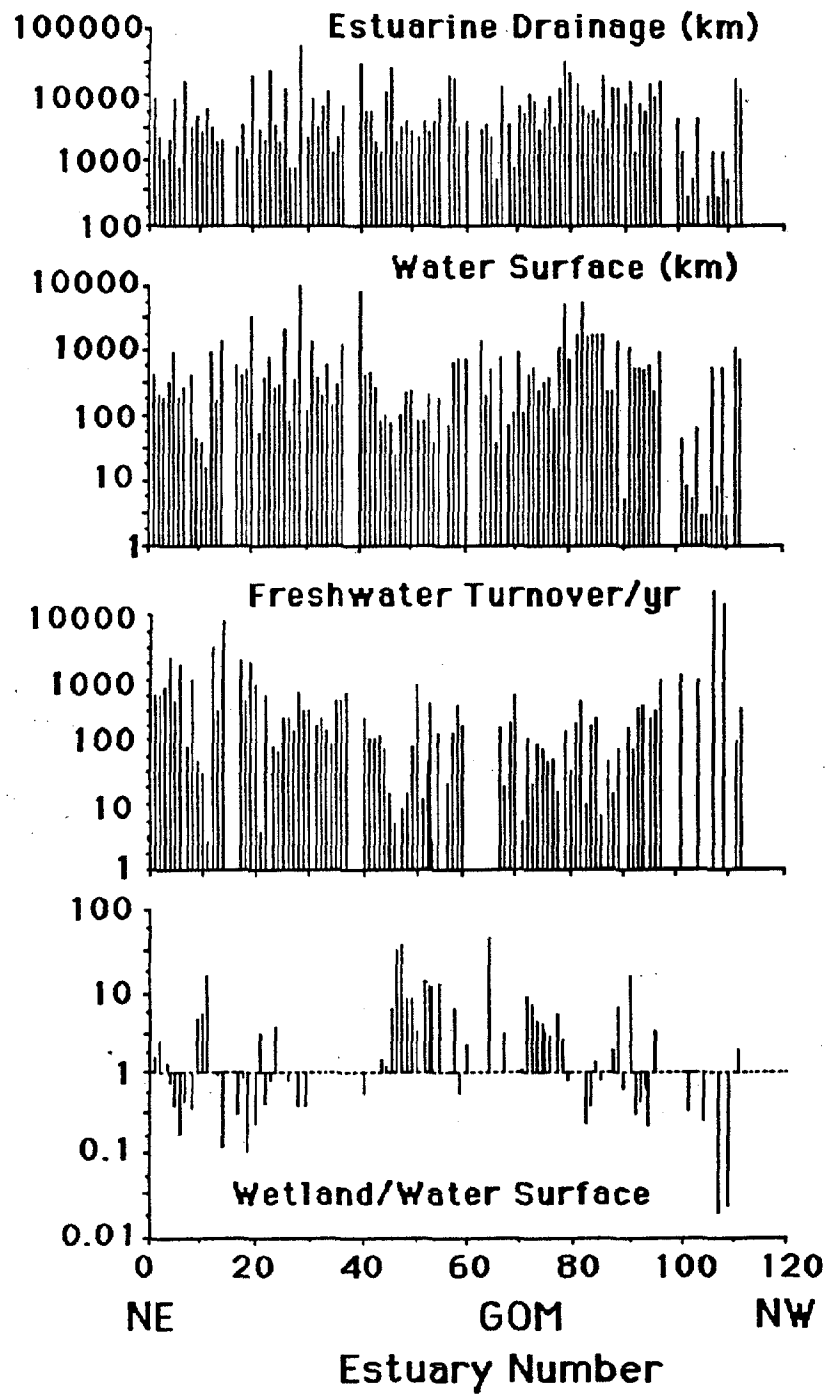


Figure 1. Variations in the morphology of US estuaries.

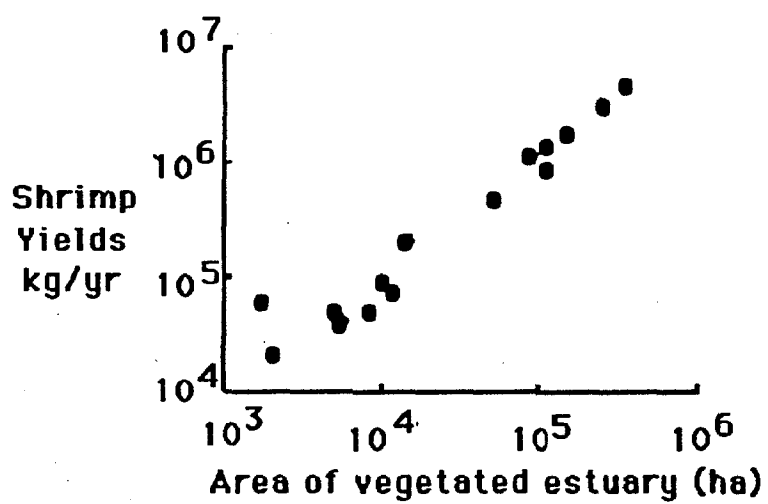


Figure 2. The relationship between intertidal vegetation and penaeid shrimp yields from the estuaries of the northern Gulf of Mexico (adapted from Turner and Rabalais 1992).

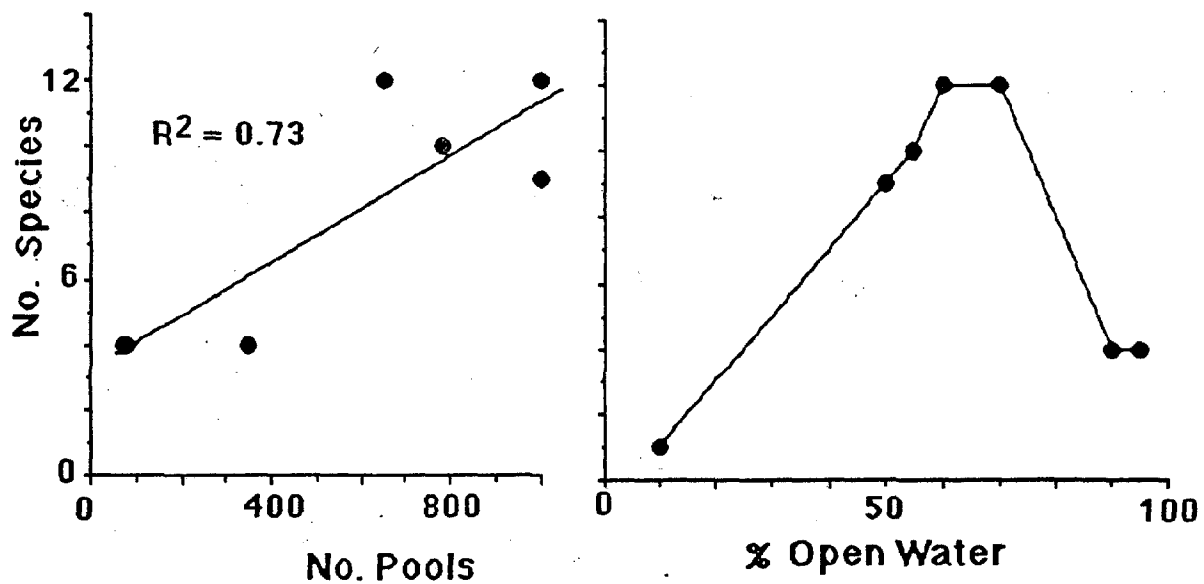


Figure 3. Species richness of birds in freshwater ponds in relationship to cover-water ratios expressed as (1) the number of pools in the emergent marsh, and, (2) the percent open water. (Adapted from Weller and Fredrickson 1974).

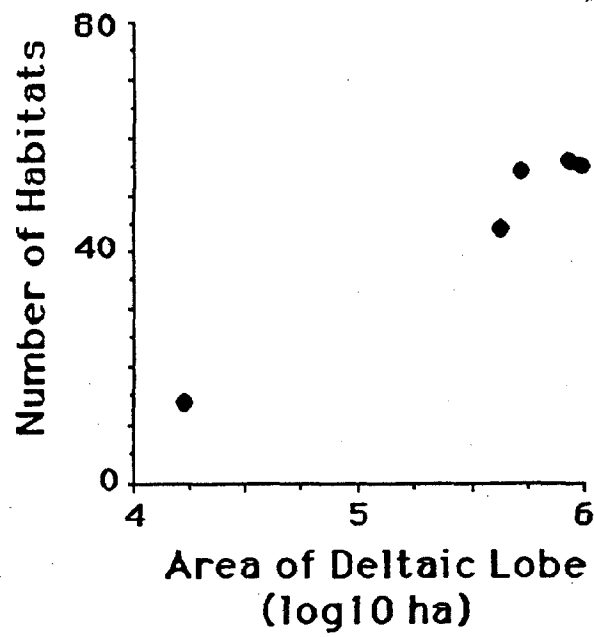


Figure 4. Habitat number vs size of the Mississippi River deltaic coastal plain (adapted from Neill and Deegan 1986).

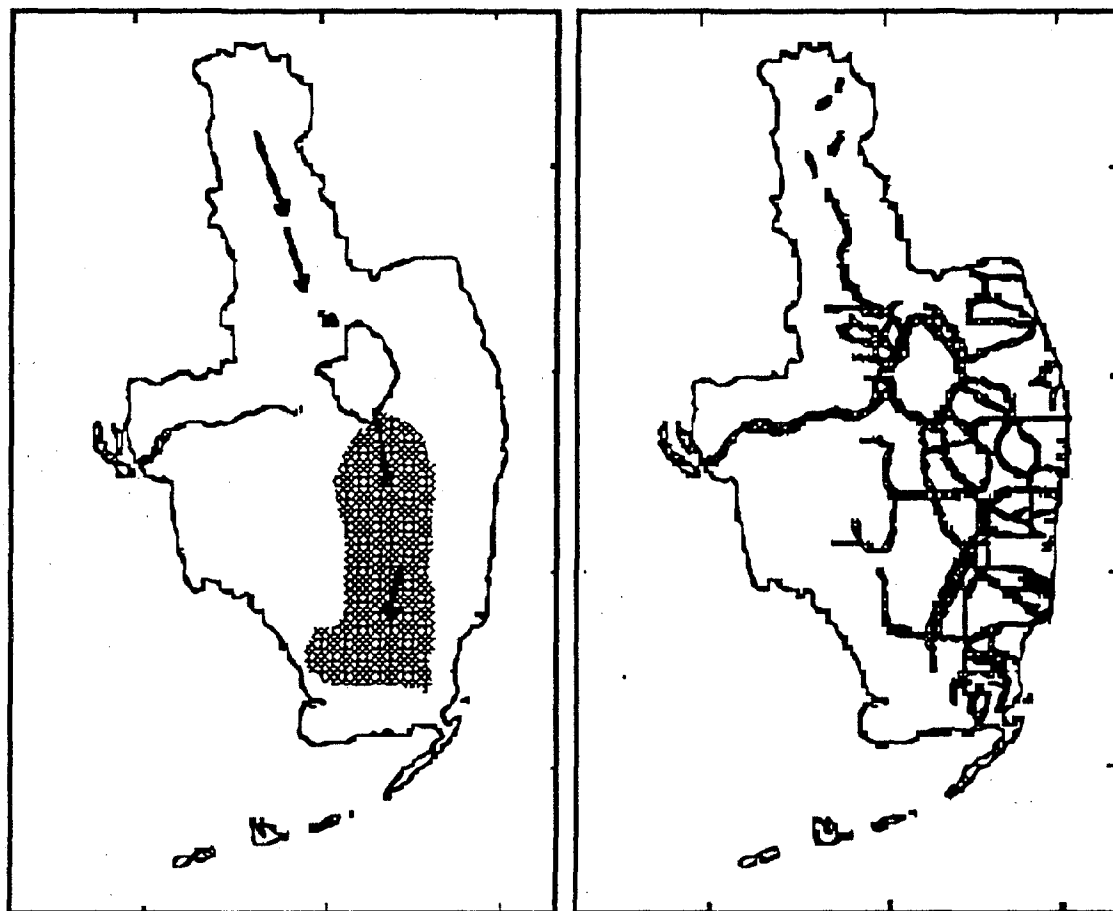


Figure 5. The hydrology of south Florida around 1900s (left) and presently (right).

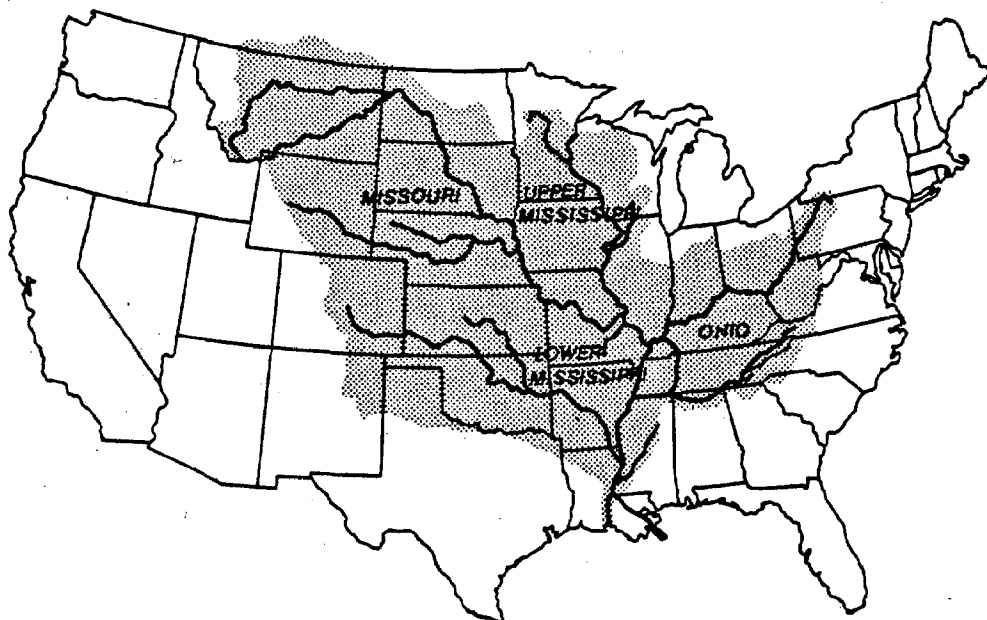


Figure 6. The drainage basin of the Mississippi River.

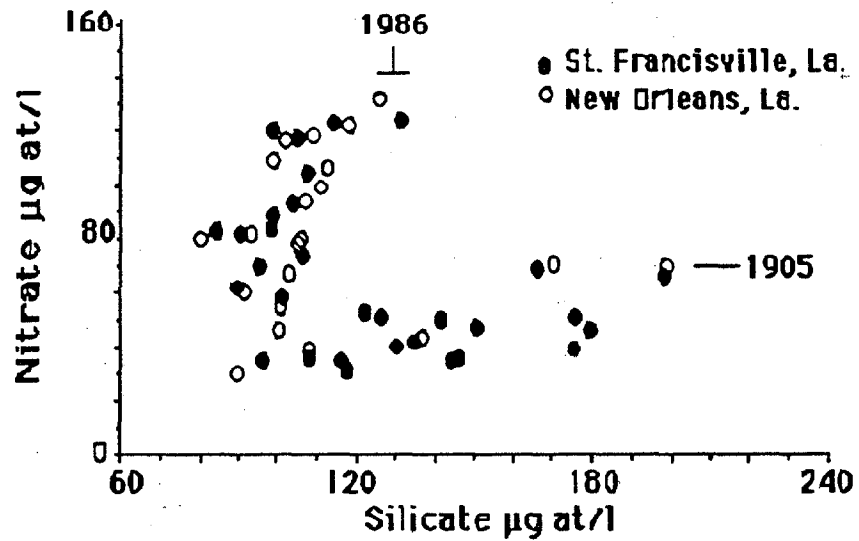


Figure 7. Average annual nitrate and silicate concentration in the lower Mississippi River. The data are from U.S. Geological Survey and the New Orleans Water Board. Further details are in Turner and Rabalais (1991).

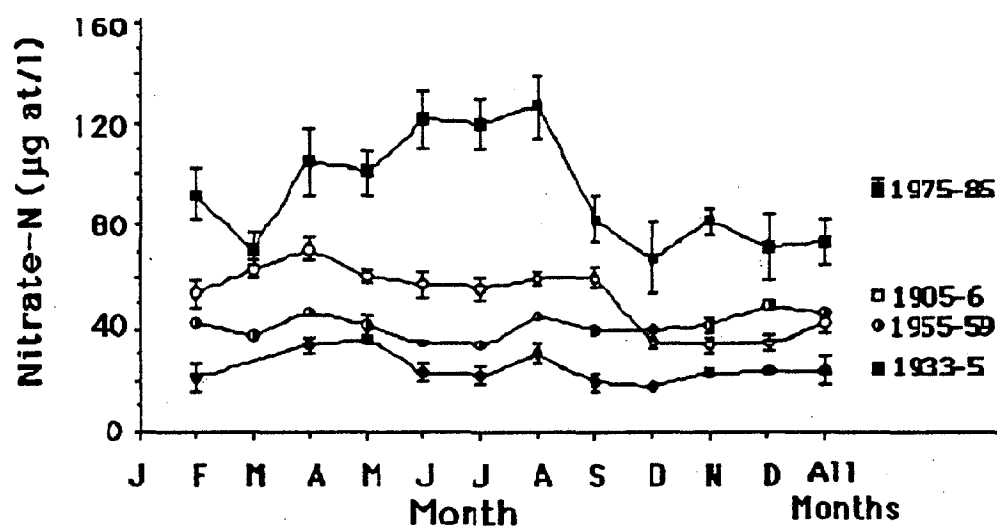


Figure 8. Seasonal nitrate concentrations in the lower Mississippi River. A ± 1 standard error of the mean is shown. Further details are in Turner and Rabalais (1991).

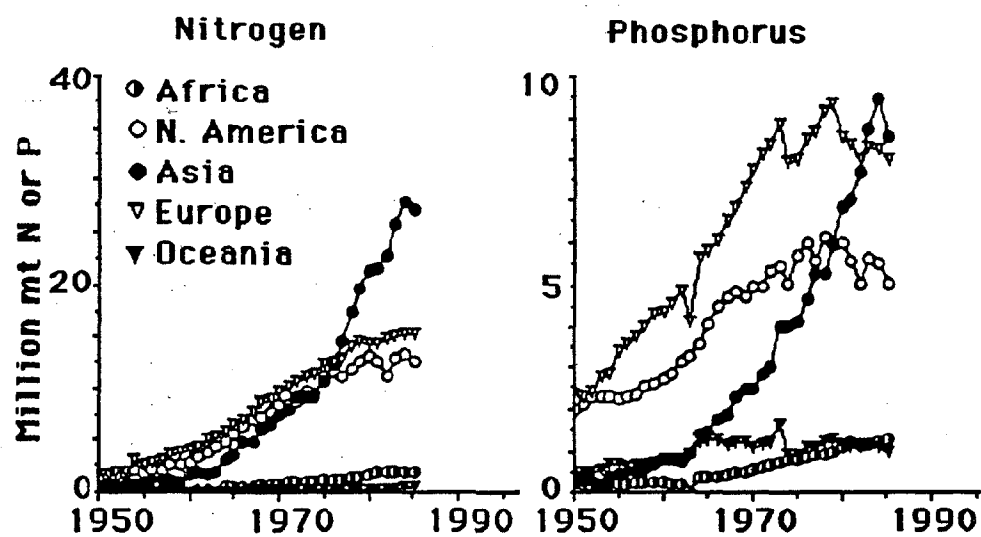


Figure 9. World and nitrogen and phosphorus fertilizer consumption since 1950. Further details are in Turner and Rabalais (1991).

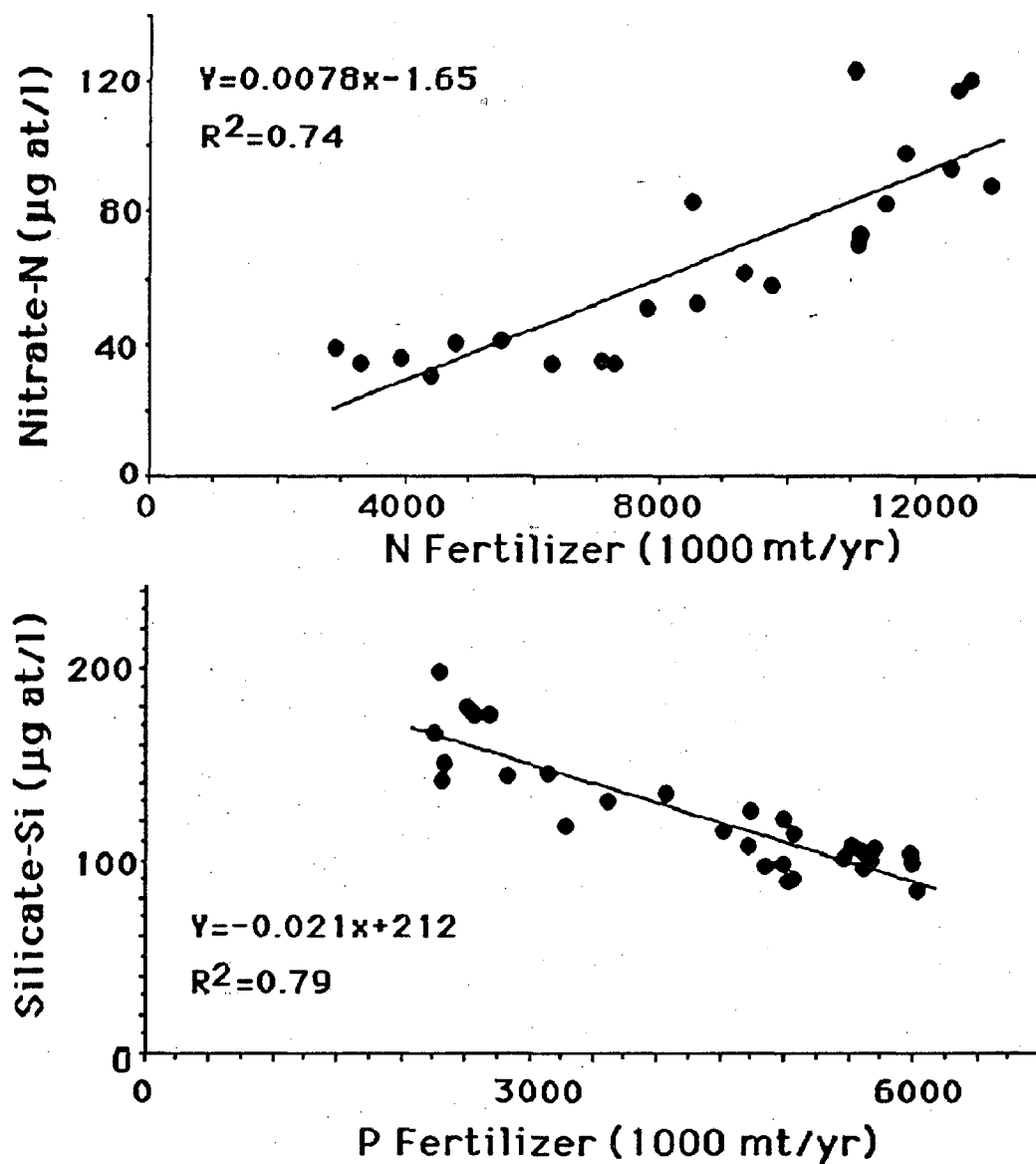


Figure 10. The relationship between fertilizer use and water quality at St. Francisville, La. Top: Nitrogen (as N) fertilizer use in the U.S. and average annual nitrate concentration from 1960 to 1985; Bottom: phosphorus (as P_2O_5) fertilizer use in the U.S. and average annual silicate concentration at St. Francisville, La., from 1950 to 1987. Further details are in Turner and Rabalais (1991).



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Figure 11. Aerial photograph of Louisiana coastal wetland. The dredged canals are usually straight and the spoil is piled alongside in a continuous line.

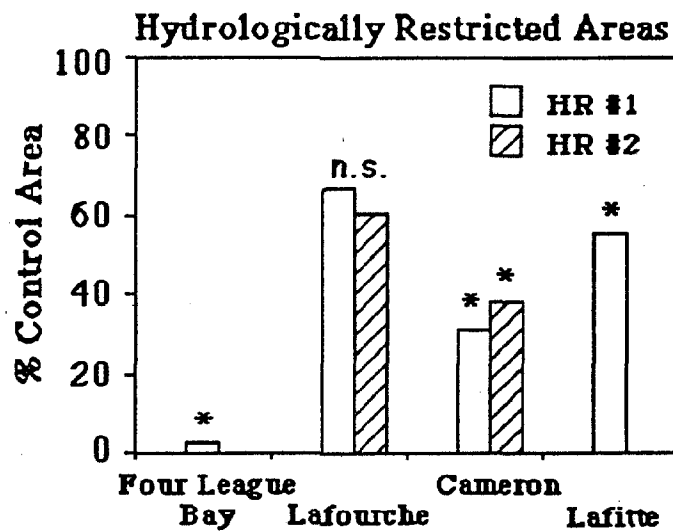


Figure 12. Vertical accretion rates in four hydrologically restricted areas (HR #1 and HR #2) compared to control sites nearby. Data were normalized to the control site values (100%). A "*" by the bar indicates a statistically-significant difference between the hydrologically-restricted site and the control site. Adapted from Cahoon and Turner 1989.

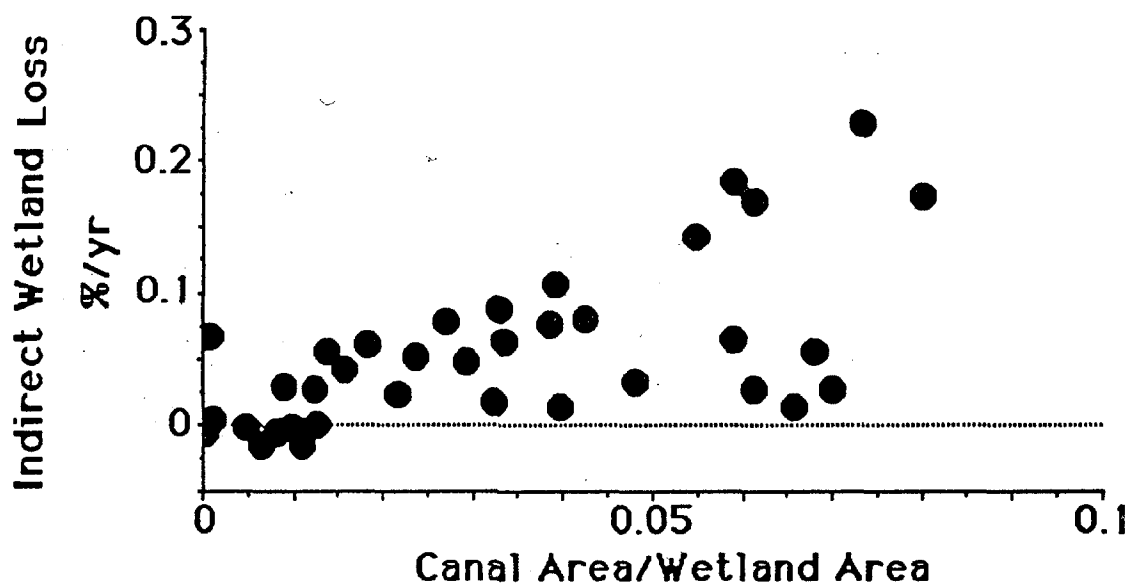


Figure 13. The relationship between canal density and indirect wetland loss rates (wetland change excluding the area lost to canals and development). Area calculations are for changes within 7 1/2' quadrangle maps from 1955 to 1978 for the St. Bernard, Barataria Bay and Terrebonne Bay estuaries. Only areas with more than 25% wetland in the quadrangle maps are included. Total area included = 413,000 ha.

Table 1. Drainage issues in South Florida (based mostly on Davis 1943 and Parker et al 1955, Anon 1948, Stephens 1969, Tebeau 1971).

pre 1920's	unregulated waterlevel in Lake Okeechobee. Lake size larger than present, filled more of its basin, and wider fluctuations in water level than presently. Water did not overflow until >20.5 msl, and over the southern rim. When water flowed the lake, the Everglades were already wet before the overflow in late summer or early fall.
1940	peat fires more frequent, soil oxidation even to bare rock is obvious, concern about relationship of 1935 and 1939 freeze and how air temperature is related to water level
1950	the St. Lucie Canal and Caloosahatchee Canal and River system are artificial outlets diverting water from Lake Okeechobee to the Atlantic and Gulf of Mexico, respectively. Rainwater is major source of water for Everglades. Saltwater intrusion into the freshwater aquifer below msl is evident (e.g. Dade County).
1970s	coastal ground-water levels significantly reduced from the 1940s (e.g. Klein 1973); Big Cypress waterflow changed from slow, prolonged southward sheetflow overland to accelerated and shortened-period runoff through canal system; water quality problems (e.g. algal blooms) in Lake Okeechobee. The 'rainfall' plan went into effect guaranteeing water to the Everglades on a regulated basis
1990	more than 1,400 miles of canals. Cattails found on 6,000 acres of Loxahatchee Wildlife Refuge (WCA-1) and another 24,000 acres show elevate phosphorous levels; various restoration efforts underway, including the restoration of the Kissimmee River Basin; annual flow distribution in Shark Slough (the a principle water entry point into the Everglades National Park) changed from a mixed east/west pattern, to almost exclusively western slough (Johnson and Ogden 1990). Lake Okeechobee water levels now 12.6 to 15.6' msl, compared to +18 to 20' msl at the turn of the century; flow over the southern rim is vastly restricted

Table 2. Some consequences of recent hydrologic changes to south Florida coastal communities.

Species	Natural Conditions	Recent	Notes
1. Area:	100%	36% urban/agriculture 32% impounded 12% overdrained	
2. Hydrology			
•hydroperiod:	gradual	shorter	
•water height:	seasonal	higher in impoundments seasonality reduced	
•Atlantic diversions:	minor	major	
3. Alligator			
•population size:	178,000	116,300 (1971-1982)	based on computer model, M. Fleming, unpublished
•percent occurrence:	7%	19%	
•of nest flooding:			
4. Five wading birds, nesting in central- south Florida:	77-93,000 (1931-40)	9,850 (1980-89)	Ogden and Johnson 1992
5. Wood stork			
•nesting success:	78% (1953-61)	21% (1962-89)	Ogden and Johnson 1992
•colony formation: in Nov/Dec	87% (1953-69)	10% (1970-89)	Ogden and Johnson 1992

Table 3. Changes in hydrologic regime of a semi-impounded saltmarsh
(from Swenson and Turner 1987).

	<u>Control</u>	<u>Semi-Impounded</u>
Flooding		
number events per month	12.9	4.5
event length (hours)	29.7	149.9
Drying		
number events per month	11.6	4.00
event length (hours)	31.2	53.9
Mean Water Level (cm; annual average)	1.71	3.99
Volume Exchange (m ³ /m ² wetland surface)		
aboveground	0.15	0.06
belowground	0.09	0.04

COASTAL POLLUTION AND WASTE MANAGEMENT

**A Discussion Paper
(Part I)**

**Prepared for the CGER Retreat
Multiple Uses of the Coastal Zone in a Changing World
25-26 June 1992
Woods Hole Study Center**

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Marine Sciences Research Center
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"The Future Ain't What It Used To Be."

Yogi Berra

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INTRODUCTION

This paper was prepared as a background paper for the National Research Council's CGER Retreat on "Multiple Uses of the Coastal Zone in a Changing World." In it I describe the major problems facing the coastal zone throughout the world and in the U.S. and review some of the priorities identified by the research and environmental management communities.

In the oral presentation I will concentrate on suggestions for improving our understanding of the processes that characterize the coastal zone and society's impacts on it; and on how we might improve the use of science to conserve and, where necessary, to rehabilitate the coastal zone and its living resources. I have chosen this strategy not only because the litany of problems and associated research needs of the Coastal Ocean are well documented, but because I am convinced that scientists must do a far better job of applying what we know if we expect to improve the condition of the Coastal Ocean and the climate for funding for the kinds of basic research that are needed. The issues I raise are not all thoroughly documented and statements often are not substantiated. The paper and the presentation are intended to provoke discussion.

WHAT ARE THE MAJOR PROBLEMS OF THE WORLD'S COASTAL OCEAN?

The Joint Group of Experts on Scientific Aspects of Marine Pollution (GESAMP), an advisory group to the United Nations, periodically assesses the problems of the World Ocean. In their most recent report (1991) they pointed out that while man's "fingerprints" are found throughout the World Ocean, the open ocean is still relatively clean, but that there are serious problems in the Coastal Ocean. The report states:

"In contrast to the open ocean, the margins of the sea are affected almost everywhere by man, and encroachment on coastal areas continues worldwide. Irreplaceable habitats are being lost to the construction of harbors and industrial installations, to the development of tourist facilities and mariculture, and to the growth of settlements and cities... If left unchecked, this will soon lead to global deterioration of the marine environment and of its living resources."

GESAMP (1991) summerized the major problems of the World Ocean as

- (1). nutrient contamination,
- (2). microbial contamination of seafood,
- (3). disposal of debris (particularly plastic debris),

- (4). occurrence of synthetic organic compounds in sediments and in predators at the top of the marine food chain,
- (5). oil in marine systems, mainly the global impact of tar balls on beaches and the effects of spills in local sheltered areas, and
- (6). trace contaminants such as lead, cadmium and mercury when discharged in high concentrations.

They added that radioactive contamination is a public concern. They did not consider items (5) and (6) above to be particularly important globally. In the summary of their findings, they stated:

"We conclude that, at the start of the 1990s, the major causes of immediate concern in the environment on a global basis are coastal development and the attendant destruction of habitats, eutrophication, microbial contamination of seafood and beaches, fouling of the seas by plastic litter, progressive build-up of chlorinated hydrocarbons, especially in the tropics and sub-tropics and accumulation of tar on beaches."

"... not enough attention is being given to the consequences of coastal development, ... actions on land continue to be taken and executed without regard to consequences in coastal waters."

The GESAMP assessment is a global assessment of the entire World Ocean and its coastal component. It's clear that their concern for the future of the World Ocean is concentrated on the threats to the margins.

WHAT ARE THE MAJOR PROBLEMS OF THE U.S. COASTAL OCEAN?

Each year the 23 coastal states, jurisdictions and interstate commissions must report, for their estuarine waters, degradation that has reached the point that estuarine areas no longer fully support designated activities.

In the most recent State Section 305(b) report to the U.S. Environmental Protection Agency, the 23 coastal states, jurisdictions and interstate commissions reported that

- nutrients accounted for 50%¹ of the total impaired area of estuaries,
- pathogens accounted for 48% of the total impaired area, and
- organic enrichment/low D.O. accounted for 29% of the total impaired area.

¹ The percentages total more than 100% because more than one stressor contributes to impairment of an area.

The states cited municipal wastewater discharge as the most extensive single source of pollution to their estuarine waters. It accounted for 53% of the total impaired area. Non-point sources may have been underrepresented in their assessment.

It is clear that the problems of the U.S. Coastal Ocean, and the causes of those problems, are similar to those of the coastal zone of the rest of the world. The first order problems are eutrophication, pathogens, and habitat destruction. All are caused primarily by an increasing population and their waste disposal practices and by changing land use patterns.

POPULATION AND ITS EFFECTS

The earth's population is now estimated to be nearly 5.5 billion and is projected to grow to more than 10 billion by the year 2050. Throughout the world, approximately half of all people live in coastal regions.

The increasing world population and the preferential settlement in coastal regions will only exacerbate the problems of the Coastal Ocean. Since 95% of the projected population growth will come in developing countries -- countries with little or no infrastructure to manage human and industrial wastes -- the most serious coastal zone problems will be in developing countries.

Throughout the United States, nearly half of the population lives within 50 miles of the coasts of the oceans and the Great Lakes. Population in U.S. coastal areas has increased by about 30 million people over the last three decades and this growth accounts for almost half the total U.S. population increase over that period. The U.S. coastal population is expected to continue to increase, although at reduced levels (Culliton et al., 1990). By the year 2010, the coastal population of the U.S. is projected to increase by almost 60%. Within coastal regions, people will continue to cluster near estuaries.

Estuarine and coastal areas not only are among the Nation's most populous areas, they also are among the nation's most densely populated areas. Population densities are highest in the counties of the Northeast and Pacific regions of the U.S. which together account for 28% of the nation's total population. The Northeast region, which extends from Virginia to Maine, is the most densely populated of the 5 regions (NE, SE, GL, GOM, Pacific). It contains 18 of the 25 most densely populated counties in the entire U.S., and 6 of the Nation's 7 leading states in coastal county population. The distribution of population in the U.S. is shown graphically in Figure 1.

As population in coastal regions grows, the Coastal Ocean loses. The greatest losses will occur in developing countries unless preventive measures are taken quickly.

The Joint Group of Experts on Scientific Aspects of Marine Pollution (GESAMP) wrote in 1991:

"The exploitation of the coast is largely a reflection of population increase, accelerating urbanization, greater affluence and faster transport -- trends that will continue throughout the world. Controlling coastal development and protecting habitat will require changes in planning both inland and on the coast, often involving painful social and political choices."

As the GESAMP report points out, protecting coastal habitat will require planning not only on the coast, but inland as well. For some estuaries, such as Chesapeake Bay, that planning must extend throughout much of the drainage basin. In others, such as Long Island Sound, the area of terrestrial influence is more constrained and planning and management can be concentrated in the coastal zone. For each coastal system, the zone of influence of human activities needs to be identified and become the basic planning and management unit.

According to Goldberg (1990), tourism accounts for about 10% of the world's gross national product. In many developing countries tourism is the main source of income. In coastal countries much of the tourism is dominated by water-related activities. Some of these same developing countries are experiencing the world's most rapid population growth rates. Few have the resources -- fiscal and technical -- needed to construct, maintain and operate the infrastructure needed to handle the wastes, particularly the human wastes, of their burgeoning populations. Typically, sewage is discharged raw into near coastal waters causing a serious public health threat to bathers and to those who consume raw or partially cooked shellfish. The potential for major epidemiological outbreaks is high and growing.

There are other environmental impacts of discharging raw or improperly treated sewage into coastal waters, particularly into bays, estuaries and lagoons. The added nutrients can produce eutrophic conditions leading to loss of submerged aquatic vegetation, to shifts in plankton assemblages, to degradation of coral reefs, and in the extreme, to hypoxic or even to anoxic conditions. The most popular beaches and coastal environments and the tourists they attract are increasingly at risk.

The coastal areas at greatest risk are in developing countries. They can and should be identified now and steps taken to assist those countries in protecting them. Priority should be given to protecting those coastal areas that are still in good condition. Preventive environmental medicine is a far more effective and less costly strategy than restorative environmental medicine.

SOME TRENDS IN U.S. COASTAL WATERS

A widely held perception is that the Coastal Ocean is in rapid decline. Let's review quickly some of the data on contaminants and pathogens for U.S. estuaries.

Contaminants

A 1990 report by NOAA's National Status and Trends (NS&T) Program summarizing six years of data on chemical contaminants in sediment and tissues states "... it appears that, on a national scale, high and biologically significant concentrations of contaminants measured in the NS&T Program are limited primarily to urbanized estuaries. In addition, levels of those contaminants have, in general, begun to decrease in the coastal U.S."

Even the higher levels in urbanized estuaries "... are generally lower than those expected to cause sediment toxicity, and among the NS&T sites, biological responses to contamination, such as liver tumors in fish or sediment toxicity, have not been commonly found." "... most contaminants measured in the NS&T Program may be decreasing. Except possibly for copper, there is little evidence that they could be increasing."

The chemical measured in the NS&T Program are metals (Cd, Cr, Cu, Pb, Hg, Ag and Zn) and organic compounds (tDDT, tCdane, tPCB and tPAH). The NOAA Status and Trends sampling sites are intended to be "representative"; hot spots are avoided.

Pathogens

The National Shellfish Sanitation Program (NSSP) classifies shellfish-growing waters to protect public health. It is a cooperative program involving states, industry and the federal government. Since 1983, the NSSP has been administered through the Interstate Shellfish Sanitation Conference (ISSC). The NSSP requires states to classify shellfish-growing waters according to approved protocols into four categories: Approved, Conditionally Approved, Restricted and Prohibited.

Data from 1985 and 1990 are summarized in Table 1. The pollution sources affecting shellfish-growing areas in 1990 are summarized in Table 2.

The data in Table 2 indicate the effects of coastal development on classification of shellfish-growing areas between 1985 and 1990. According to NOAA (1991) the largest increases in closures are attributed to urban runoff increasing from 23 to 38% of harvest-limited waters. The acreage adversely affected by septic systems increased from 22 to 37%. NOAA attributed the increasing effects of septic systems to the continuing growth of tourism and vacation homes. The impacts of boating rose from 11 to 18%.

Nutrients

I am unaware of any systematic summaries of the trends of nutrients in U.S. coastal waters. I expect that levels in many estuaries are increasing, primarily because of increased populations. In Long Island Sound, over the past 50 years the non-point source input of nutrients from agriculture has declined, but the non-point source input from creeping suburbanization has increased. Over the same period, the point source inputs from New York City treatment plants has been relatively stable, but not point sources in coastal counties bordering the Sound have increased significantly. Over-enrichment of Long Island Sound by nitrogen is considered by the Long Island Sound Study to be the most important hazard to the Sound ecosystem. In 1991 New York and Connecticut signed a pact to cap nutrient inputs at 1991 levels and to work to decrease the input. To maintain nutrient inputs to the Sound at 1991 levels -- levels which are already too high -- a significant investment will be required in the future -- even in a region that now has one of the slowest population growth rates in the Nation. Schubel and Pritchard (1991) estimated that in the year 2050, it would require an additional removal of 20-25% of the nitrogen to honor the 1991 cap.

The Top 10 Pollutants in Estuaries

Figure 2 shows the State Section 305(b) assessment of the top 10 offenders (pollutants) of the Nation's estuaries in terms of their contributions to total impaired area. The sources of pollution are shown in Figure 3.

One Person's List of the 11 Worst (Most Degraded) Estuaries and Near Coastal Regions

If pressed to come up with the "Big 11" of the nation's most degraded estuaries and coastal regions based on: (1) levels of pollutants in bivalves (clams, oysters, mussels) and sediments, (2) hypoxia/anoxia, (3) depleted and closed fisheries, (4) prevalence of fish diseases, (5) areas closed to shellfishing, (6) areas closed to swimming, and (7) warnings concerning consumption of fishery products, the following would make my UNRANKED list of coastal areas of greatest concern:

- Boston Harbor
- Narragansett Bay
- Buzzards Bay
- Western Long Island Sound
- Baltimore Harbor
- Upper Chesapeake Bay
- Hampton Roads/Elizabeth River (Chesapeake Bay)
- Lower Mississippi and inner delta
- Galveston Bay
- San Francisco Bay
- Portions of Puget Sound

WHAT RESEARCH PRIORITIES HAVE BEEN IDENTIFIED?

Most of the most serious problems of the Coastal Ocean are fairly well documented. There are few surprises. In this section we consider briefly the extent to which research priorities reflect these problems.

Over the past two decades there have been a series of workshops to identify the research "needs" for estuaries and near-coastal waters. Often these workshop retreats were held in idyllic spots; they always included many of the leading scientists. Whether the workshop was held on Block Island, Catalina Island, or Long Island, whether it was in North Carolina or in East Anglia (UK), the lists of research priorities were remarkably similar. This is not surprising; the problems of the coastal zone are pervasive and persistent, and many of the participants were repeaters. What is surprising is the lack of improvement in the richness with which the specific questions have been formulated, and the evolution of the research programs to attack them.

The results of some of these workshops are summarized in Table 3 using a U.S.A. Today, "McPaper" format. The consensus on priorities is clear. If another workshop were held in 1992-- and I'm not advocating it -- the list would differ little. If a workshop were to be held, it could more profitably concentrate on a single priority issue of long-standing, such as eutrophication, state the research problems more richly and give more specific guidance for formulation of a research program to advance the level of our understanding. It should be structured to build partnerships with decision makers, from the outset, to utilize the new knowledge.

SOME POTENTIAL EFFECTS OF GLOBAL WARMING

While the major direct effects of global warming on the coastal ocean will not be on "coastal pollution and waste management" there may be some indirect effects. And, since I have the floor...

Sea Level

Half of the world's population lives in coastal regions, many of which are already under stress. Eustatic sea level has been rising for approximately the past 18,000 years. Regionally, the rate of rise of sea level may be either greater or less than the world-wide average because of regional isostatic adjustments. An increase in the rate of rise of sea level because of global warming will have its greatest impacts on low lying coastal areas already subject to flooding. As much as 20% of the Earth's population lives on lands that would likely be inundated or dramatically changed. Bangladesh and Egypt are among the nation's most vulnerable to a rise in sea level. But, they are not alone.

An interesting example of a nation that would be impacted are the Maldive Islands. This archipelago of about 1190 small islands lies approximately 6100 km southwest of Sri Lanka. Most of the nation rises only 2m above sea level. In 1987 Maldive's President Maamoon Abdul Gayoom went before the U.N. General Assembly and described his country as *"an endangered nation."* He pointed out that the Maldivians *"did not contribute to the impending catastrophe... and alone we cannot save ourselves."*

Tidal wetlands may be one casualty of an increase in the rate of rise of sea level. Wetlands -- particularly youthful wetlands -- are able to maintain themselves in a rising sea either by building vertically by trapping sediment and organic detritus or by moving landward. In many developed coastal areas, the lateral migration of wetlands has been halted by shoreline structures and by coastal construction. In others, the supply of sediments has been reduced because of better soil conservation practices and construction of reservoirs.

Titus (1990, 1991) stated that if current management practices continue and if sea level rises as projected, most of Louisiana's wetlands could be lost in the next century. These and other reports have indicated that a 1m rise in sea level by the year 2100 could drown 25-80% of all U.S. coastal wetlands.

Salt water intrusion into coastal aquifers and greater penetration of salt water into estuaries may threaten drinking water supplies.

Increased Frequency and Intensity of Storms

Because of the large concentrations of people in coastal areas, risks to life and property because of coastal storms are already high and will increase with population and sea level rise. According to NOAA, a conservative estimate of the average economic costs of coastal hazards in the U.S. is about \$2 billion/yr. However, Hurricane Hugo, alone, caused more than \$9 billion in property damage and economic losses within the U.S. and its possessions.

If global warming causes a rise in sea level and increases the frequency and intensity of storm activity, flooding and storm damage to low-lying coastal areas will, of course, increase with an increased loss of property and human lives. Damage would be particularly great in delta regions of South Asia.

There will be other impacts of an increase in storm activity on coastal regions; most bad, a few perhaps good. Coastal infrastructure will be at greater risk: sewage treatment plants, airports, power plants, and even the subways of some coastal cities, for example. Increased storm activity also could increase the disturbance of contaminated sediments and the mobilization of contaminants. On the positive side, increased wind mixing of coastal waters by greater storm activity might alleviate the effects of hypoxia in some areas such as Long Island Sound and the New York Bight.

SOME OVER-LOOKED PROBLEMS/PROCESSES

A number of coastal problems/processes have not received an appropriate level of attention. These include: non-point sources, including the atmosphere; pathogens; eutrophication; and the manipulation of river discharges on coastal ecosystems. Because of limitations of space and because land-derived non-point sources are beginning to receive far more attention, I will restrict my comments to atmospheric inputs and to the manipulation of river discharges.

You may be wondering how the latter relates to my assigned topic -- "coastal pollution and waste management." According to GESAMP (1991), *"marine pollution means the introduction by man, directly or indirectly, of substances or energy into the marine environment (including estuaries) resulting in such deleterious effects as harm to living resources, hindrance to marine activities including fishing, impairment of quality for use of seawater and reduction of amenities."* In this case, salt is the pollutant; it comes from the ocean, but man allows more of it to enter because of manipulation of the hydrologic cycle. As fresh water inflows are decreased, salt penetrates farther into estuaries destroying low salinity habitat.

Manipulation of River Discharge: A Looming

One set of problems which has received too little attention and which may become more serious in the future are the effects of manipulation of river discharge on estuaries and near-coastal waters. If global climate change results in regional scale changes in precipitation patterns, in those areas where precipitation decreases, the coastal environment may be the big loser. When the value of water is high and when there is not enough to go around, as in California, the coastal environment has not competed successfully in the water allocation game.

The U.S. continues to have a voracious appetite for water. While it does not lead the world in any of the reported categories of water use (public, industry, electric cooling and agriculture), in the aggregate the U.S. has the highest per capita water use and the highest total water use of all countries. China is second in total water use and Canada is second in per capita water use.

A small number of rivers dominate the discharge of water to the World Ocean. One river, the Amazon, accounts for more than one-third (34.6%) of the total water discharge of all the world's rivers. The Congo River ranks second with 6.9% of the total. Twenty-one of the world's rivers account for more than 90% of the total discharge; four for more than 50%.

The human activity that has the greatest effect in reducing the discharges of water and sediment by rivers has been the construction of dams and reservoirs. They have also affected the pattern and timing of discharges. In Africa and North America, 20% of the total discharge is regulated by

reservoirs; in Europe 15% and in Asia -- excluding China -- 14% is regulated. Only in South America and in Australasia are human impacts on river regimes relatively minor. According to Croome et al (1976), *"Some ten percent of the world's total stream flow now is regulated by men, and by the year 2000 it is probable that about two-thirds of the total discharge will be controlled."*

While the prediction of Croome et al. may be an over-estimate -- and I believe it is -- the regulated fraction of the world's river discharge will increase and changes in regional precipitation patterns could have an influence.

The most intensive period of dam-building activity was between 1945 and 1971 when more than 8,000 major dams were built outside of China (Beaumont 1978). The year of peak activity was 1968 when 548 dams were commissioned. Beaumont's (1978) data do not include China which in 1982 accounted for more than 50% of all the world's dams, most of which were constructed after 1950 (Schubel, et al. 1991). The U.S. ranks second in total number of dams, Japan third.

Reservoirs also trap sediment which would normally be carried downstream to coastal areas. Prior to construction of the Hoover Dam (1935), for example, the Colorado discharged between 125-250 million t.y⁻¹ of sediment to the Gulf of California. In the decades after closure of the dam, the discharge dropped to only about 100,000 t.y⁻¹ -- to 0.05 - 0.1% of pre-dam levels (Meade et al. 1990).

Construction of dams on the Missouri nearly eliminated the discharge of sediment of the Missouri to the Mississippi River -- its major source of sediment. Partly, as a result of this, the sediment discharge of the Mississippi has fallen to less than half of what it was before 1953 (Meade et al. 1990).

The Aswan High Dam on the Nile River is perhaps the most striking example of the effects of a dam on the sediment and water discharges of a major river. After closing of the dam in 1964 the sediment discharges of the Nile to its delta dropped from an average of more than 100 million t.y⁻¹ nearly to zero. The delta has been eroded and fisheries have collapsed.

The reductions in discharge of freshwater and sediment to estuaries and the reductions in the variability of freshwater inputs have effects on physical, chemical and geological processes of estuaries and on their ecosystems. As competition for fresh water increases, the needs of estuaries will be weighed against the needs -- real and perceived -- of humans for water for drinking and domestic use, for agriculture, for cooling water, for electric generating stations and for industry. In the absence of compelling arguments, estuaries will lose. They will be unable to compete successfully in the marketplace for freshwater unless the rules are changed to place a

greater emphasis on the public trust doctrine and on the importance of preserving estuarine habitats.

Perhaps the Precautionary Principle is the place to begin. The Precautionary Principle can be stated in terms of the need to take a cautious approach to any actions that might degrade the environment and its living resources even before a causal link has been established unequivocally. The Precautionary Principle has to apply in all situations, not just in those where high priority activities are not threatened. If the Precautionary Principle were a guiding principle in the allocation of fresh water from the Sacramento-San Joaquin system in California, it is difficult to see how further diversions would be considered even in the absence of an unequivocal causal link between diversion and adverse effects on ecosystem values and functions in the low salinity portion of the estuary.

In the 1981 National Symposium on Freshwater Inflow, Rosengurt and Hayes (1981) stated *"Direct experience and the published results of the effects of water development abroad, all point to the inescapable conclusion that no more than 25-30% of the natural outflow can be diverted without disastrous ecological consequences."* Their observation was based upon studies of rivers entering the Azov, Caspian, Black and Mediterranean Seas. In the same report, Clark and Benson (1981) state *"Comparable studies on six estuaries by the Texas Water Resources Department showed that a 32% depletion of natural freshwater inflow to estuaries was the average maximum percentage that could be permitted if subsistence levels of nutrient transport, habitat maintenance, and salinity control were to be maintained."* Again in that same report Bayha (1981) indicated that results of studies by the Cooperative Instream Flow Service Group of the U.S. Fish and Wildlife Service "square well" with the observations of Rosengurt and Haydock.

The 25-30% criterion for maximum allowable reduction in natural riverflow does not have widespread acceptance among scientists or decision makers. According to Herrgesell et al. (1981) discharge of freshwater into San Francisco Bay has been reduced by approximately 50% since the 1800s. Other sources put the reduction at 70%. Some have predicted that inflows could be reduced to 10-15% of pre-diversion levels by the year 2000. Even with the major reductions that have already occurred, estuary managers and scientists face a formidable challenge in convincing the State Water Control Board that further reductions cannot be tolerated.

Clark and Benson (1981) suggested establishing optimal salinity regimes and associated hydrologic regimes within estuaries. Bayha (1981) pointed out that although estuarine needs are included among instream uses, few instream flow studies have actually incorporated an analysis of estuarine inflow requirements to ensure estuarine ecosystem values and functions.

The San Francisco Estuary Program is developing the scientific basis for a salinity standard to conserve low salinity habitat and living resources. The standard would take the form of an upstream seasonal limit for the position

of the 2‰ near-bottom isohaline (Schubel et al. 1991). Even the discussion of a salinity standard has created concern.

The Atmosphere -- An Underestimated Source of Contaminants to the Coastal Zone?

The atmosphere may be underestimated as a source of a number of contaminants to coastal waters, particularly in urban areas such as Long Island Sound. While data specific to Long Island Sound atmospheric loadings are limited, preliminary estimates indicate that for a number of contaminants (Cu, Pb, Zn, PCBs, PAHs) direct atmospheric deposition on the Sound may be of the same order of magnitude as the inputs from point and non-point sources. For example, analysis of atmospheric deposition rates of a variety of contaminants on high marshes bordering the Sound suggest that the atmosphere supplies (1) 90% of all Pb, (2) 35% of all Zn, and (3) 70% of all the Cu supplied to the Sound from all sources (Merkle and Brownawell, in press).

The implication is that for some urban coastal areas, the Clean Air Act may be more important than the Clean Water Act in reducing the levels of a number of contaminants.

ON THE NEED FOR NEW PARADIGMS

This will be the topic of my oral presentation and I will distribute copies of my notes at the Retreat. My working hypothesis is that without new paradigms for research aid for research in support of coastal management, the future of the Coastal Ocean -- at least its inshore portions -- is bleak.

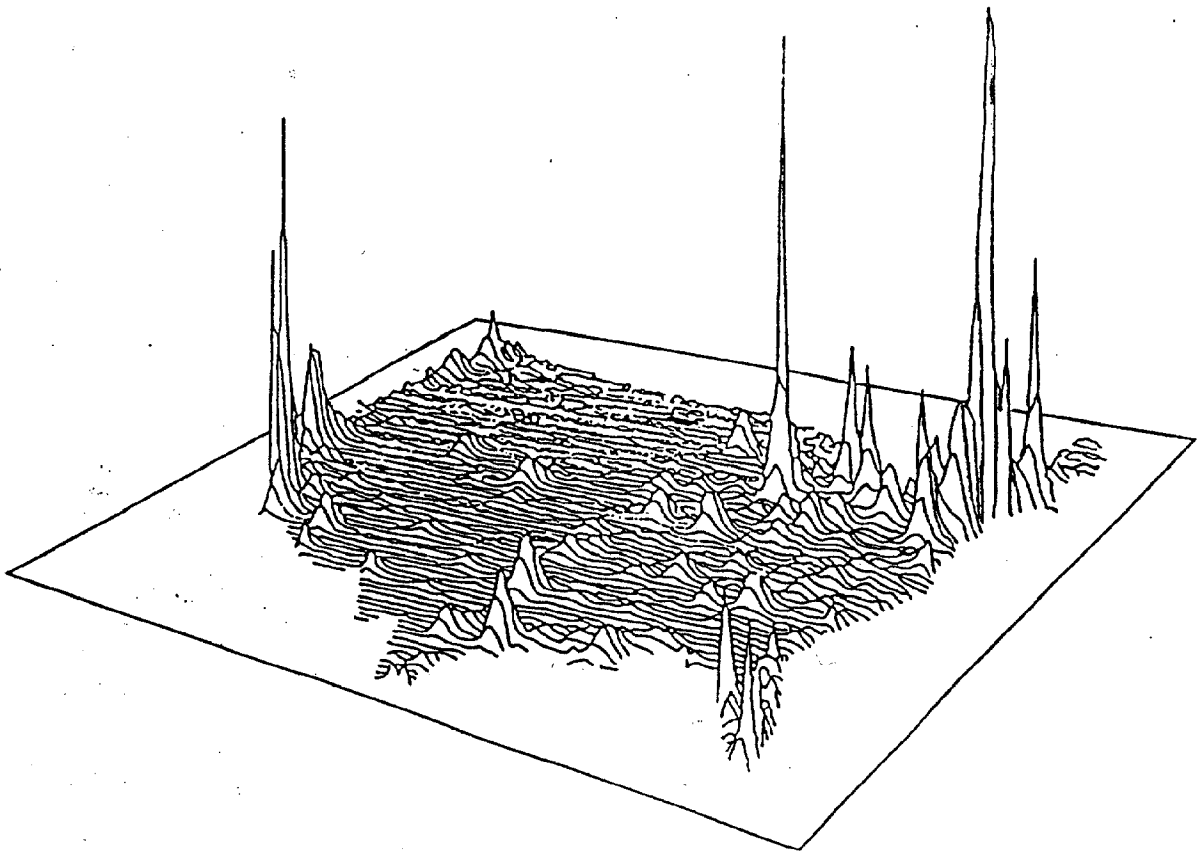


Figure 1. Distribution of Population in the U.S. by Region
(Laboratory for Computer Graphics and Spatial Analysis, Harvard)

Table 1. Distribution of Classified Estuarine Waters, 1985 and 1990

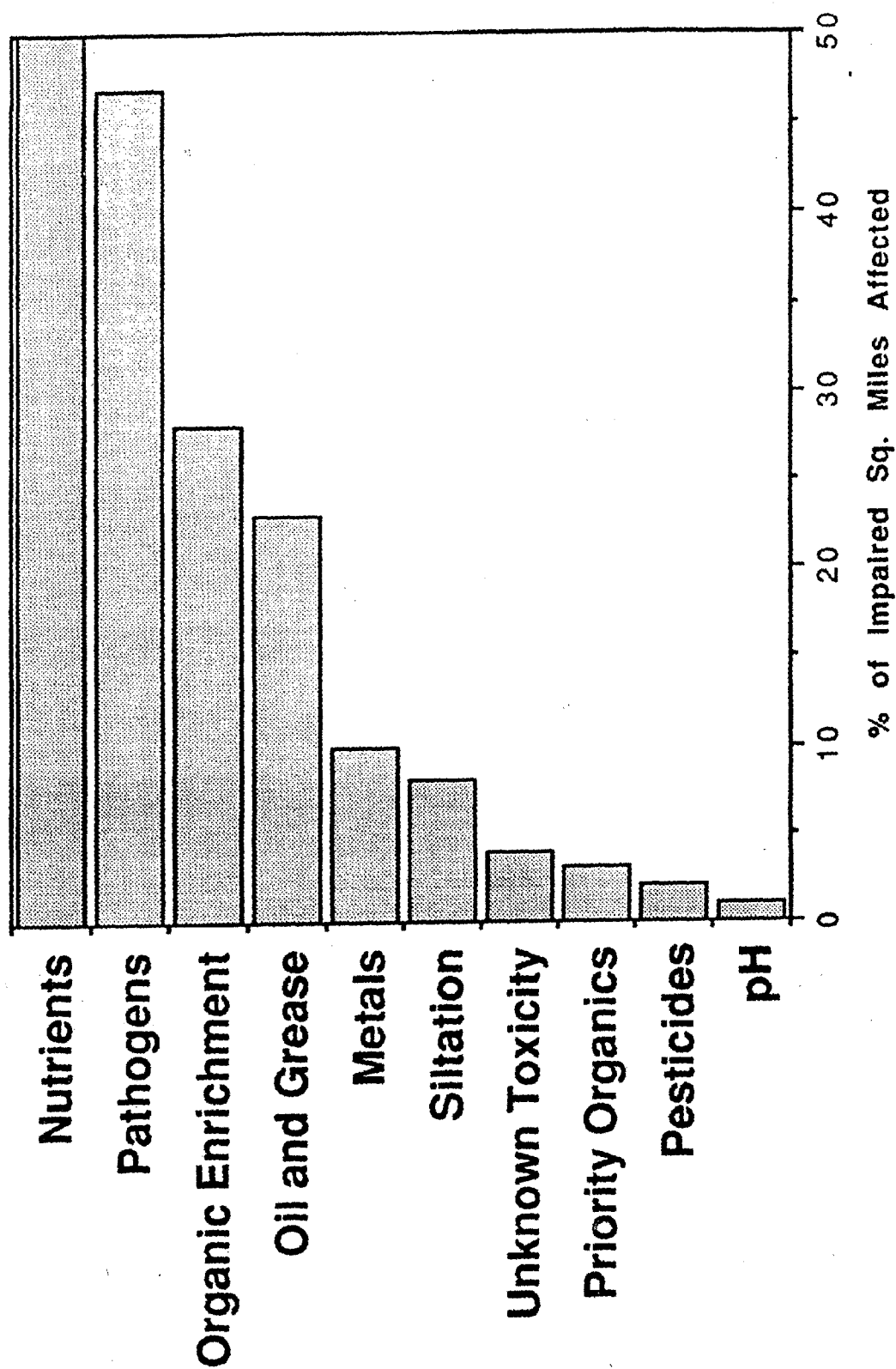
	Percent Classified							
	Approved		Prohibited		Conditional		Restricted	
Region	85	90	85	90	85	90	85	90
North Atlantic	87	69	10	29	1	1	2	1
Middle Atlantic	82	79	11	13	3	4	4	4
South Atlantic	75	71	22	21	3	4	<1	4
Gulf of Mexico	54	48	24	34	17	16	6	1
Pacific	42	53	40	31	18	11	1	5
Total	69	63	19	25	9	9	4	3

Table 2. Pollution Sources Affecting Harvest-Limited Acreage, 1990 a,b

	North Atlantic		Middle Atlantic		South Atlantic		Gulf of Mexico		Pacific		Nationwide	
	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%
Point Sources												
Sewage Treat Plants	238	67	641	57	374	44	973	27	75	25	2,307	37
Combined Sewers	21	6	224	20	0	0	211	6	0	0	457	7
Direct Discharge	1	<1	84	7	5	1	920	25	6	2	1,015	16
Industry	21	7	223	20	180	21	522	14	129	42	1,077	17
Nonpoint Sources												
Septic Systems	91	26	123	11	288	34	1,763	48	57	19	2,322	37
Urban Runoff	75	23	655	58	290	34	1,276	35	110	36	2,412	38
Agricultural Runoff	5	3	130	12	233	28	301	8	41	13	718	11
Wildlife	19	7	112	10	306	36	1,115	30	39	13	1,597	25
Boats	55	17	353	31	146	17	507	14	47	15	1,113	18
Upstream Sources												
Sewage Treat Plants	2	1	104	9	9	1	1,174	32	45	16	1,334	21
Combined Sewers	0	0	5	<1	0	0	134	4	0	0	0	2
Urban Runoff	3	1	72	6	8	1	793	22	43	14	918	15
Agricultural Runoff	0	0	1	<1	0	0	435	12	0	0	436	7
Wildlife	0	0	28	2	35	4	210	6	0	0	273	4

a. Acres are times 1,000; % is percent of all harvest-limited acreage in region.

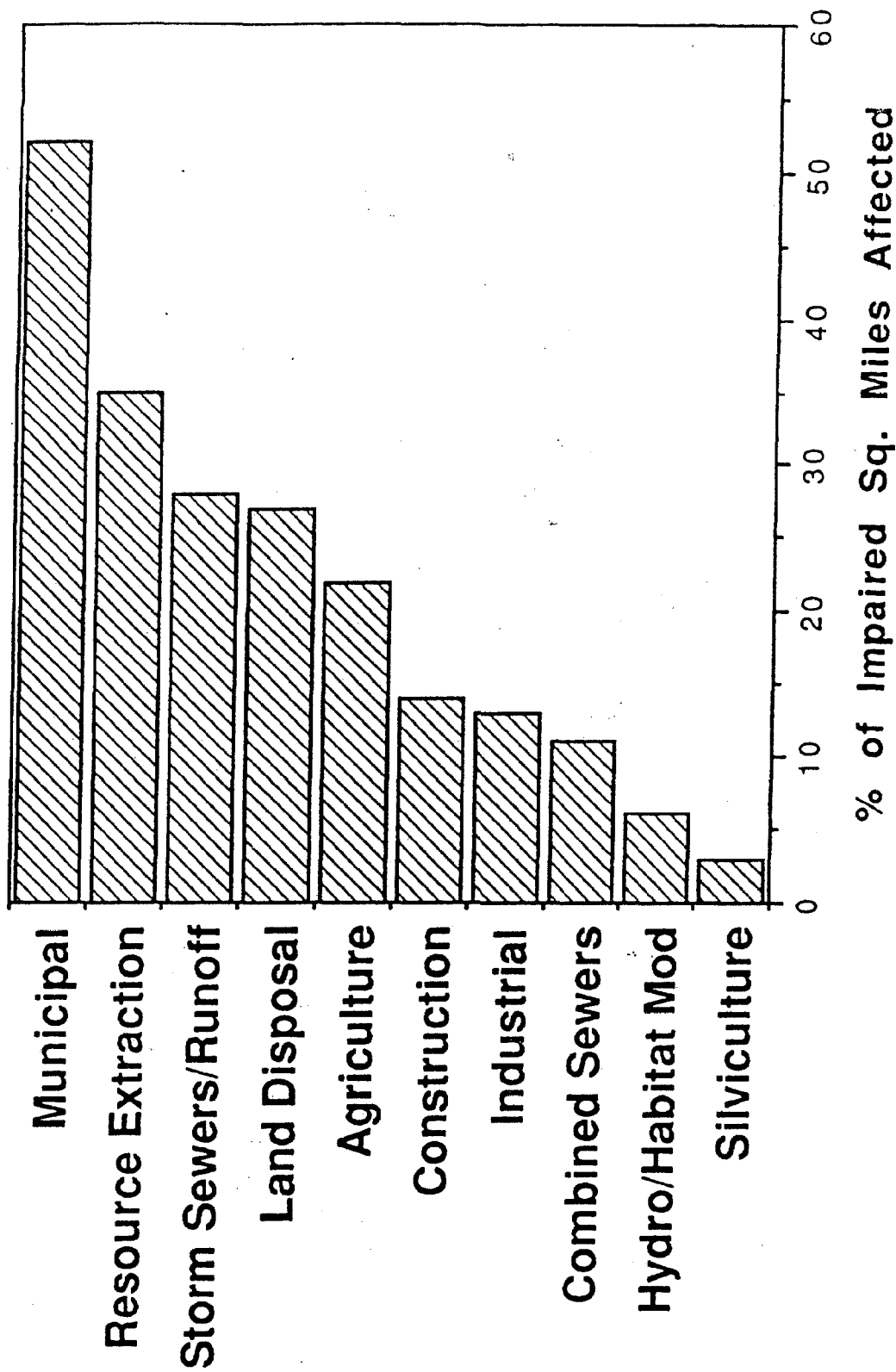
b. Since the same percentage of a shellfish area can be affected by more than one source, the percentages shown above cannot be added. They will not sum 100.



Top Ten Pollutants in Estuaries

Figure 2.

Source: USEPA, 1990. The Quality of Our Nation's Water.



Sources of Pollution in Estuaries

Figure 3.

Source: USEPA, 1990. The Quality of Our Nation's Water.

TABLE 3
ESTUARINE RESEARCH PRIORITIES, 1974-1990

Research Priorities	NSF 1974	NRC 1977	NERC 1982	CRC 1983	NRC 1983	Hudson River 1984	Sea Grant 1984	NASULGC 1986	NOAA 1986	ASLO 1990	MSRC 1990a	MSRC 1990b
• Sediment Management	X	X	X	X			X	X	X	X	X	X
• Behavior of Suspended & Dissolved Matter		X	X	X	X			X	X	X		X
• Resuspension; Remobilization; Role of Physics, of Biota	X	X	X	X						X	X	X
• Water Management							X	X	X			
• Circulation & Mixing	X	X	X		X			X		X		X
• Toxics & Other Contaminants		X		X		X	X	X	X		X	
• Eutrophication	X	X		X			X	X	X	X		
• Habitat, Fisheries Prod.				X	X	X	X	X	X	X	X	
• Behavior & Fate of Particulates		X	X					X	X	X		X
• Population, Community			X	X				X		X	X	
• Anoxia/Hypoxia		X	X	X				X	X			
• Monitoring			X	X		X		X				
• Coupling of 1° and 2° Production						X	X		X			
• Plumes & Fronts		X	X									X
• Data Management				X				X			X	
• Sources of Carbon			X						X	X		
• Waste Management		X		X								
• Air-Water Exchange	X											
• Global Warming									X			

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Coastal Management and Policy

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This paper is one of several prepared for a retreat on coastal zone issues sponsored by the NRC Commission on Geosciences, Environment, and Resources. A number of papers discuss focused technical aspects of the coastal zone such as ocean circulation and coastal meteorology, and others deal with broader subjects such as: 1. coastal wetlands, coastal/nearshore littoral systems; 2. land use and the coastal zone; and 3. coastal pollution and waste management. The topic of this paper "Coastal Managment and Policy" inevitably touches on aspects of each of the others. In an effort to minimize the duplication of discussion, I will specifically address three topics which are generic in nature. The first concerns the question of how we are organized to provide governance of the coast. Second, I will discuss several problems this system encounters as it translates science into policy. Finally, I touch upon the question of how human values and expectations affects the problem of coastal managment. In the conclusion I will offer a suggestion for improving the development of policy for the coast and its management.

I. The Governance System

Perhaps the most salient feature about coastal governance in the United States is the extraordinary degree to which it is fragmented.¹ This fragmentation exists in two dimensions which have important ramifications.

In consequence of our federal system of government and a concurrent fierce attachment to local authority, coastal governance is divided among at least three levels --- federal, state, and local. (Increasingly, the international agenda adds a significant additional level of authority for coastal matters)

* In some instances the governance authority is exclusively held primarily at only one level of government. For example, land use controls in the interest of flood or erosion management generally are exclusively exercised, if at all, at the local level, while management of navigational systems is largely a federal responsibility.

* Other instances are found where authority may be simultaneously and separately exercised by two levels of government. For example, in many states, activities to

1. There are a number of intellectual or policy efforts to overcome this fragmentation. They include such ideas as integrated permitting and inspection and sustainable development.

regulate development in wetlands are carried out by both the states and the federal government.

* There are models of governance which provide for the delegation of authority from one level of government to another. Thus, the Federal Clean Water Act provides for delegating most federal authority to the states, and this has been done in many regions of the country.

* In some circumstances the same resource may be regulated by a different level of government depending upon the geographical region of the coastal zone in which it is located. Many species of fish are regulated pursuant to a federal system when located offshore, but the same species (and individual) may be regulated by state authorities when it migrates to fresh water rivers.

* Authority may exist at different levels of government with respect to a particular issue depending upon the function being performed regarding that issue. Thus, the responsibility for constructing domestic sewage treatment plants is generally at the local level, while the responsibility for setting minimum standards and (until recently) raising the necessary funds was a federal one.

In addition there are any number of ways in which these three levels may choose to combine in order to regulate or manage a particular coastal resource or activity. Two or more states, perhaps with the federal government and/or local authorities, may

join together in an interstate compact to create new authorities to manage a particular resource or activity. This has been common for interstate bodies of water and for regional port facilities. They may also reach more informal arrangements which are designed simply to assure a high degree of coordination of multi-jurisdictional activities --- the Chesapeake Bay Program is a classic example.

The subject-matter, or issue, fragmentation of coastal governance adds further complexity. Responsibility for various substantive issues is always widely distributed among a very large number of government organizations at every level. The extent of this fragmentation is well known and need not be repeated. There are, however, several characteristics that are worth mentioning.

* In many cases this dispersal of authority is not crisp. There tends to be a certain gradation in responsibility from one agency to the next. For example, while EPA is clearly responsible for non-point source water quality issues and also manages the nation's national estuary program, the Department of Commerce through NOAA and Coastal Zone Management Act responsibilities also has non-point source water quality functions, as does the Department of Agriculture through the Soil Conservation Service. The blurring of authorities and responsibilities as one moves from the core function of one agency to that of another can

have the disadvantage of diffusing authority. On the other hand, it can also allow for competition among agencies to do a good job.

* Even where governments have attempted consolidation in order to eliminate fragmentation of governance, success has been rare. Very large organizations with a multiplicity of missions tend to be internally diffuse. Furthermore, it is simply not possible to combine everything. Recognizing these short-comings, the tendency during the early nineteen-seventies to create "super" agencies seems to have ended. A notable exception is the recent effort of California to create a unified Department of the Environment. Even within that strengthened Department, water quality management responsibility is geographically divided among a number of very strong regional water boards. And, coastal management per se is located in the separate Resources Department.

The foregoing has largely focused on a discussion of the fragmentation problem within and among the executive branch of governments. It is important to note that, at least at the federal level, the problem of fragmentation within the legislative branch of government is also severe. There are well over thirty subcommittees of the Congress responsible for matters relating to the coastal environment.

II. Using Science to Inform Policy and Action

While fragmented systems of governance have contributed mightily to the current poor management of U. S. coastal resources, the many problems associated with properly focusing science on the policy choices has been as harmful. The problem of the relationship between science and policy is not unique to the coast and has been extensively treated by a number of authors. The essential question is how to organize scientific information in a fashion which is understandable to policymakers and which compels an effective management response even though the information itself is imperfect. There are some peculiar aspects of the coastal marine environment which make this problems even more severe. They do bear some discussion.

In the first instance, most of what goes on in the marine environment is invisible to all but the most sophisticated and dedicated investigator. This invisibility condition makes it almost impossible for the citizen or policymaker to have any intuitive sense of the actual condition of the resource as it may be described by the scientific community. Lacking this, a sense of reality and even urgency, where warranted, is missing. A useful comparison between the effects of invisibility of the marine environment and visibility in the terrestrial environment is found in the Chesapeake Bay. During the decade of the nineteen-eighties, over 80 % of the bay's submerged aquatic

grasses died. Scarcely anyone noticed. Imagine the public reaction if 80 % of the forest resources of the Bay's watershed had died during the decade. Lack of visibility of marine processes also means that sometimes what is observed can be distorted far beyond the actual importance which the observed event may have scientifically. Thus the washing up of a relatively small number of syringes on the beaches of New Jersey during the summer of 1988 crystalized a public impression which may have been far removed from the scientific reality.

Secondly, the actual science of the coastal environment is extraordinarily complex. Crucial processes take place in the atmosphere, on the land, and within the water. They may be immediate, a watershed away, or, as in the case of El Ninjo, half a world away. They can be physical, chemical, biologic, or some combination of the three. Much about these relationships is not well known. In addition to the extreme complexity of the natural systems, the possible ways in which human activities can intrude are even more complex. They range across the full conduct of economic and recreational life not just in the coast but throughout the watershed, from pollution, to fisheries, to development in flood plains, to habitat destruction for homes, to materials used such as pesticides for agriculture. The sum is hugely complicated and it has only been in the last ten years that society has really begun to think of the total interaction in anything like a science-based systems way. This inevitably

means that for some time to come, most questions about the nature and causes of the problems of the marine environment will be answerable in only the most tentative and perhaps inconclusive terms. This poses serious problems to policy-makers seeking to allocate scarce resources as well as to the public which is looking for the certainty of environmental protection.

Finally, the inherent complexity of the marine environment and its relationship to land-based activities, makes the problem of cumulative impacts especially severe. All too often adverse environmental consequences take place far in the future as a result of a large number of relatively minor activities. Often the eventual adverse environmental event is dramatic in nature and nearly irreversable. For example, it is difficult to assess the impact on the coastal environment of the conversion of any individual farm or wood lot to a tract housing complex. Yet, there are numerous instances where sidespread conversions across a region have resulted in the general decline of coastal resources, and specifically, perhaps the loss of important shellfish resources.

Just as governance has been fragmented, the practice of the science of the marine environment (as much other environmental science) has been fragmented and myopic. For science to be most effective in the face of uncertain knowledge, it needs to develop information from as wide a range of disciplines as

possible and search for the integrating themes which begin to illuminate paths for action. For a variety of reasons, this kind of science is neither valued by the academic community nor often sought by the government.

III. Public Values and Roles

There is no single public nor is there a uniform set of values regarding the coastal environment. While there is great diversity, a common driving interest can be seen. That common interest is use. Various parts of the public will tend to define their objective for management in terms of whether the use they make of the coastal environment is protected. Fishermen and seafood consumers will want to be assured that seafood is safe to consume. Surfers and swimmers will want to be certain that it is safe to swim in the water. Those who appreciate the enjoyment of the marine environment, such as bird watchers, will want to know that the ecological system is healthy and viable. Commercial and recreational fisherman will expect that the productive quality of the marine environment is protected.

In summary the public will have the following objectives:

- * fish and shellfish which are safe to consume;
- * water which is safe to come into contact with;
- * a healthy ecological system; and
- * a productive ecological system.

The foregoing suggests that there is not a simply stated set of public objectives for coastal environments. This diversity is a reasonable situation since there are divergent perspectives depending upon the viewpoint of the particular participant in the discussion. No view can be seen as wrong when analyzed from the stance of its own interest and the societal values which it seeks to advance or protect. However, the very fact of the variety of interests and sources of threats suggests one basis of a complex process of risk analysis and priority setting.

A factor which further complicates this already murky picture is that the mix of these various values changes constantly with time. Values held by particular interests can change and the relative importance which is ascribed to different values by society can change. In addition, the objective factual setting will evolve. Scientific understanding and technological capacity do grow. Choices about risk will vary. The net result, however, during this century, has been a steadily growing body of knowledge about the extent to which the environment is being damaged and steadily growing public demand for improved levels of environmental protection.

IV. Conclusion

There are severe consequences flowing from this fragmented and complex system of governance. Of course, there are the usual

problems of waste, duplication of effort, lack of coordination on common problems, and conflicting political agendas. While serious, these are not the most important consequences of the current fragmentation of coastal governance. More important problems are:

- * a collective failure to identify the most important threats to the quality of the coastal environment;
- * failure to design a responsive management strategy which allocates scarce resources to the most critical problems;
- * occasional massive attention to a high-profile condition which, even when resolved, will still not solve the identified coastal problem;
- * an inability for public attention to focus on one political entity as responsible and accountable for the improvement of the coastal environment; and
- * a distortion of science with the result that the clarity of positive actions becomes murky.

In essence, this all means that: 1.) unwise actions are often taken; 2.) responsibility and accountability for the wise management of coastal resources is diffuse; and 3.) the process is often inaccessible to concerned publics.

There have been a limited number of efforts to improve this situation. At the federal level, the only significant attempt was the enactment of the Coastal Zone Management Act in 1972. It can be argued that this statute provided the opportunity for the

federal government to initiate a process of forging at the state level a system of governance which would meld the disparate functions into a coherent whole. However, this opportunity was generally missed as the federal program only sought to achieve a state coastal program designed around a system of loosely coordinating various authorities. The result has been that separate authorities remain dominant and that common actions are still lacking.

Solutions to these problems can be found through implementation of a governance strategy based on the concepts of integrated coastal management. In brief, integrated coastal management is a methodology which identifies important scientific and human-value issues on an ecological basis, compares the risks posed, and develops risk management options which effectively allocate scarce resources to the most important problems. This dynamic process is action oriented and iterative with refinements being based on monitoring, research and institutional responses.

The first step in actually implementing such a strategy would be to identify a single governmental entity to be assigned with the actual responsibility of assuring that integrated coastal management is carried out. This does not mean that all governmental functions must be combined in one "superagency." In highly complex or geographically widespread situations, it may

mean that new coordinating bodies need to be established. In either case, in order to be effective the responsible entity should have the following authorities: planning for integrated coastal management; monitoring for environmental results; coordinating of budgets; and data management.

Background Paper:

Workshop on "Multiple Uses of the Coastal Zone in a Changing World"

**Research and Development Funding for
Coastal Science and Management
in the US**

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Introduction

It is an indisputable conclusion that coastal ecosystems are important to society, yet many are stressed and require remedial action, and conserving the remaining values is unpredictable. It is not surprising, therefore, that various strategies and planning exists to achieve the desired goals for these systems. However, after decades of much work and financing, these goals are still elusively sought in the case of most coastal systems. While old pressures continue, new ones arise (e.g. aquaculture, eutrophication and sea level rise), yet the natural attributes and 'controlling circuitry' are still incompletely understood. Two activities are still necessary: the development of new knowledge, and, the application of that knowledge.

Both scientists and engineers (S&E) are involved in these two activities. It is the purpose of preparing this material to examine important funding patterns and cross-sectoral interactions among government, education and industry. This is done to help evaluate and devise recommendations affecting how we - managers, administrators, scientists and engineers - may more usefully contribute professionally. We used mostly national statistical parameters because coastal scientists and engineers are obviously not a distinctive tribe, professionally isolated from either their inland peers or offshore colleagues.

Where are the Coastal Scientists and Engineers?

Coastal scientists and or engineers (S&E) cannot be defined as easily as chemists or physicist, which are from more traditional discipline interests. Coastal fields tend to be interdisciplinary, may include management, and are limited to the coastal zone (which is itself undefined). Traditional societal surveys may therefore not recognize all significant participants. An American Geophysical Union (1986) occasional survey (others in 1969 and 1975) of ocean scientists and engineers was used here as an indicator of the total number of coastal S&E, and, as a descriptor of their geographic distribution.

In 1986 there were 6,000 people included in the AGU survey, which compares to the national S&E manpower of 400,358 (NSB 1991), or 1.5 % of the national S&E workforce. Eighty-five percent were in the coastal states, whose geographic distribution is described in various

ways in Figure 1. There are significant numbers of coastal S&E in all coastal states. The density per population is highest in the northeast and northwest coastal sectors (upper panel), and density per shoreline length (from the World Almanac) is highest in Maine, Alaska, and the southeastern US and Gulf of Mexico (middle panel). There are eleven institutions with more than 50 S&E among the 25 coastal states (lower panel). There is a ten-fold range from minimum to maximum in all values. There are obvious centers of concentration spread broadly within all regions of the US. All states appear to have a minimal core of S&E working in the coastal zone, however it is defined.

National Science and Engineering Issues

Coastal scientists and engineers are less than 10 % of the total US S&E manpower and their sectoral addresses (per above) are not obviously different from the rest of the national S&E workforce. National statistics may provide information, therefore, about the activities and resources of coastal S&E.

National indicators of science and engineer funding and manpower have increased tremendously since WW2. In 1940 there were 330 Ph.D.s per 1 million people older than 22 years. By 1966 that ratio climbed to 778:1,000,000, in 1970 it was 1587:1,000,000, and 2000 per million in 1990 (Stephan and Levin 1991). In 1976, S&E employment was 2.4 % of the workforce, but in 1986 it was 3.6 %. The growth of US baccalaureate and first professional degree has increased about 4.8 % annually since 1900. The new workforce is being trained today, but apparently not in sufficient quantity to meet modest projections for national needs. Various reviews (e.g. Pool 1990, Atkinson 1990, NSB 1991) suggest an "annual supply-demand gap of several thousand scientists and engineers at the Ph.D. level, with the shortage persisting well into the 21st century." (Atkinson 1990, p. 427), as an aging faculty retires, as the student population bulges, and if historical S&E employment growth continues. Employment growth for S&E, however, is not projected to remain steady, but to rise.

What is the support for the present and future graduate students? Where will we find those young S&E for work in the coastal zone?

In 1969 there were 80,000 S&E graduate students supported by Federal funds (Table 1). In 1980 and 1990 the federal support changed from 44,590 to 52,875 students (18.5 % rise), respectively, and 20 % of the total were supported on federal funds. Meanwhile, the student population rose to more than 267,621 students and the S&E workforce increased 50 %. The number of environmental students (1 to 1.5 % of the total) has declined in the past 10 years. From 1980 to 1990 total S&E expenditures increased 130 % in current dollars, and 51 % in constant 1982 dollars. Those dollars not only paid for basic salaries of a more experienced workforce, but increasingly sophisticated equipment amidst the growth of larger projects. In other words, in the past decade: (1) the dollars for R&D and S&E workforce rose together, (2) student support rose slower than total support, and, (3) the average project size per potential investigator has gone down. One consequence is that education of graduate students may be compromised. One cannot (or should not) turn students loose without supervision and they need resources to be trained.

The experience at NSF reflects these changes. The proposal success rate at NSF has gone from 38.5 % in 1981 to around 30 % in 1990 (Palca 1990). The average grant size has dropped from \$68K in 1985 to \$61.7 in 1989 (1989 dollars). Individual investigators accounted for 57 % of the research budget in 1991 budget compared to 68 % in 1980. Although centers are often blamed for the lack of small science, only 4.5 % of the NSF research budgets go to research centers. The change in average grant size has not gone unnoticed. Dalrymple (1991) quoted the V. Bush report (1945) setting up the NSF: "New products and processes are founded on new principles and conceptions which, in turn, are developed by research in the purest realms of science". The concern is twofold: (1) that directed science compromises undirected science, and, (2) that big multi-investigator projects compromise the productivity of the smaller, often single-investigator projects. The resolution of these issues affects how coastal zone science and management will proceed. There are urgent pleas to have scientists actively involved in the process of setting priorities (e.g. Kaarsberg and Park 1991) for a shrinking budget.

However, even if funding increases in the near future, it is unlikely that we will return to the days immediately following WW2, when it was said that "under present conditions, the ceiling

on R&D activities is fixed by the availability of trained personnel, rather than by the amounts of money available" Steelman 1947, p.22). Unfortunately, both funding *and* manpower appear limiting in the years ahead and the S&E community should prepare for strenuous discussions about the relative merits of big and small science, and of directed vs undirected research. In the midst of these changes appears the complicating (and compromising) growth of 'ear-marked' funds for R&D, otherwise known as 'pork barrel' projects. In 1983 there were 3 of these projects worth about 16 million (Figure 2). By 1990 the amount rose to nearly 500 million. An Office of Science and Technology Policy analysis for 1991 appropriations bills identified 492 projects totaling 810 million. For comparison, this is equal to 44 % of the NSF budget, and 6 % of the national educational R&D budget. Scientists and engineers should be wary of this development, as it is a substitute for merit review. Merit review must be effective and acceptable to be a plausible defense against pork barrel funding.

Research Product Quality

There are three major performers of research: government, industry and educational institutions. Government laboratories have a reputation for project management, monitoring and immediate problems over publication; educational laboratories for a 'publish-or-persish' reputation; and industry for garnering funds necessary for either profit or proprietary interests and for a rapid response and 'on-time' performance, etc. These three sectors have legitimate viewpoints and functions that a national research and development policy should be matched with, goal for function.

The educational community clearly excels at developing new information. Two demonstrations of this are discussed here. Analyses of frequently cited papers in ecology and oceanography are provided by McIntosh (1989) and Garfield (1987), respectively. The most frequently cited papers, indicators of highly useful scientific contributions, are dominated by authors residing or working with educational institutions (Table 2). More than 95 % of all 'classic' papers are from these institutions. Officer et al. (1981) provided a different type of analyses for selected estuarine publications. They concluded that "the academic community has produced most

(77 %) of the refereed research literature on estuaries -- evidence of the importance of academic sources of new knowledge," done on somewhere between 31 to 37 % of the available funding. A more complete quantification of 1,200 S&E publications for 1984 (NSB 1987) indicates that 61 % of all articles arose from educational institutions (Table 3; article number was proportioned according to all author's addresses). This educational contribution was done on 9 % of the funding, and was 14 % of the average dollar spent per article generated. In other words, the quality and quantity of educational research publications compares very well to all other sectors.

What is the preference of the other sectors for working with each other on new information? The overwhelming preference is for collaboration with co-authors at educational institutions (Table 4). The strongest preference across sectors was for federal scientists to work with scientists in the educational sector where nearly half of all articles from federal laboratories were co-authored with educational sector co-authors.

Terminus

Coastal science and management are not particularly overwhelmed with useful data and more data are required to address the newly arising complications of increased population, limited resources and complex management milieus. New scientific and engineering contributions are heavily weighted towards educational R&D contributions. The present R&D funding environment is stagnating, and threatened by looming manpower shortages and is very competitive. These factors are beginning to place a strain on the S&E community which is becoming increasingly vocal about the instability of funding for individuals, the size individual project funding, and the distribution of funding towards fewer and larger projects. Some see fields that are becoming "overcrowded with 'risk avoiders' more worried about their next grant" (Stephan and Levin 1991). The federal government is becoming less involved in R&D research in terms of the percent funding, publication, and student support.

It has been suggested elsewhere that it is appropriate for student support from federal sources to be doubled (J. Vaughn, "The federal role in doctoral education" a policy statement of the American Association of Universities, D.C. Sept. 1989). Doing that without depleting the other

R&D resources would have the longterm effect of increasing the labor pool in future years and to support higher education which does significant amounts of the research.

Partnerships with the educational R&D sectors should be encouraged. The R&D activity of the educational sector is of high quality, high quantity and relatively inexpensive compared to other sectors. Federal:educational linkages are pretty good, but not with all sectors. We must be careful co-mingling the different institutions so as not to compromise the qualities of each by confusing the functions of each, which are not the same. University scientists are not natural resource managers, but teachers, even scholars, and technically astute. The political demands of government service require skills that are not taught on class field trips or in the research laboratory. Time spent by government on management and administration is time not available to develop, assimilate and synthesize new information. Industrial R&D activities are more sensitive to profit, etc. What we do not know is how much more overlap of activities is desirable. The partnerships of the next few years should be interesting, in that regard, and attempted gradually.

There are some conspicuous differences between research in the coastal zone and elsewhere that should be mentioned. Research in the coastal zone is more parochial, in some ways, than in blue water oceanography, for example. In forest research there is an open competition for funds that is sometimes lacking in coastal zone research. The role of the research community in proposal review by the former has a greater role in determining quality than the estuarine research, for example. Socio-political aspects tend to be more influential in deciding what questions should be asked and how to manage an estuarine project. Although the pressure is somewhat understandable given the multiple and often conflicting views of estuarine management, the result is often 'quick and dirty' R&D projects and an undue influence of opinion about sometimes very sophisticated scientific and technical issues. Good analyses can lay out the options and their implications without involving a policy choice; good policy decisions cannot be made without good analyses. A recent example of the effect of an absence of good analysis is the debacle over redefining wetlands in the absence of scientific judgement (Kusler 1992, Sipple 1992). In this example, scientific judgements were phased out in favor of policy outcomes suiting an exclusively political

agenda. Second, it is worth repeating that good analyses do not usually come quickly, and that simple plans of actions are usually just that - simplistically inappropriate. The short-attention spans of managers and politicians amidst S&E untrained in policy makes for a treacherous liaison between what is an artificial division of 'basic' and 'applied' R&D. It is a particularly daunting challenge to derive the essentially interdisciplinary programmatic thrusts necessary to answer the management questions within the coastal zone. Third, unstable financial resources will not be as effective as long-term support. Excellence requires stability (but not entrenchment). Meeting the immediate needs of management compromises achievement of substantial gains over the long haul.

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Table 1. Changes in support for Scientists and Engineers (S&E) and graduate students in 1969, 1980 and 1990. The 1969 data is from Atkinson (1990).

Other data is from NSB (1991, p 252). Dollars in current dollars.

	<u>1969</u>	<u>1980</u>	<u>1990</u>
<u>Graduate S&E Students</u>			
<u>to Education</u>			
Federal sources (no.)	80,000	44,590	52,875
All Sources (no.)	-	215,354	267,621
% Federal	-	20.7 %	19.7 %
Environmental Students (no.)	-	3,442	2,939
% Environmental Students	-	1.6 %	1.1 %
<u>Research and Development</u>			
<u>to Education</u>			
Federal (billion \$)	1.6	4.1	9.3
All Sources (billion \$)	2.2	6.1	16.0
% Federal	71.9 %	67 %	58 %

Table 2. Addresses of authors of 'classic' journal papers in ecology and oceanography. WH and SIO are scientists whose mailing address is Woods Hole, Massachusetts and Scripps Institute of Oceanography, California, respectively. Scientists living there may, or may not, have an academic affiliation at the time of the article publication data.

<u>Source</u>	<u>US</u>				<u>Foreign</u>	
	<u>WH/SIO</u>	<u>Educ.</u>	<u>Govt.</u>	<u>Industry</u>	<u>Educ.</u>	<u>Govt.</u>
McIntosh 1989	5	61	2	1	32	6
Garfield 1987 non-core journals	22	4	0	0	2	1
Garfield 1987 core journals	10	5	2	0	7	5
Totals	37	70	4	1	41	12

Table 3. Expenditures (millions) and cost per article published by sectors for 1984. Adapted from data in NSB 1991, p 308, and NSB 1987, p 286. R&D=Research and Development.

FFRDC=Federally funded Research and Development Center.

<u>Sector</u>	<u>R&D \$</u> <u>(Millions)</u>	<u>%</u> <u>funding</u>	<u>#</u> <u>articles</u>	<u>%</u> <u>articles</u>	<u>\$1000/article</u>
University	8,617	9	30,988	61	278
Non-profit	3,000	3	5,803	11	517
FFRDC	3,150	3	1,970	4	1,599
Federal	11,572	11	8,898	18	1,301
Industry	74,800	74	2,930	6	25,529
Total	101,139	100	50,599	100	1,999

Table 4. Percent cross sectoral (Education, Industry, Non-profit, Federally Financed Research and Development Centers, and Federal) authorship of journal articles published in 1984. The items in **bold** are the two most frequent cross-sectoral associations for the authors in that sector. Adapted from data in NSB 1987, p 277.

	<u>Educational</u>	<u>Industry</u>	<u>Primary Authors</u> <u>Non-profit</u>	<u>FFRDC</u>	<u>Federal</u>
<u>Co-Authors</u>					
Educational	77	24	53	37	48
Industry	3	64	3	6	4
Non-profit	7	3	36	2	5
FFRDC	2	3	1	49	2
Federal	10	6	8	5	42

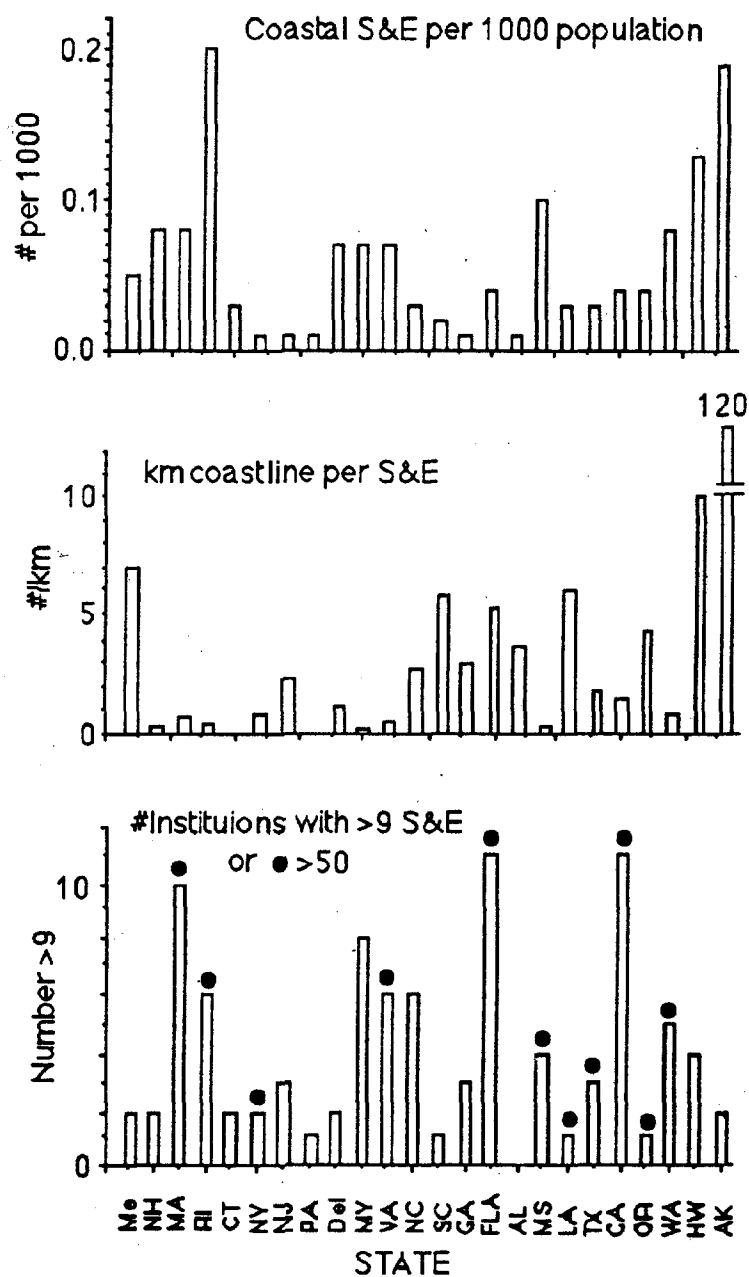


Figure 1. Geographic distribution of ocean scientists and engineers in the US coastal states. Top: coastal S&E per state population (1990 census data). Middle: Coastal S&E per km tidal coastline. Bottom: Number of coastal S&E per state. The height of the bar indicates more than 9 reside at one address. A '•' indicates more than 50 reside at one address (maximum of one in any one state). Data are from a 1986 survey of scientists and engineers (AGU 1986).

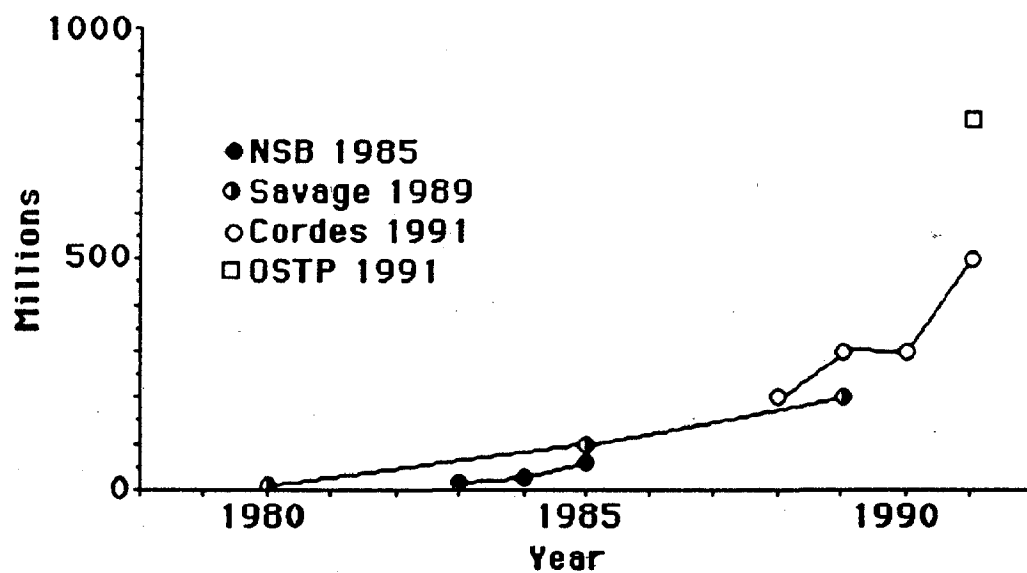


Figure 2. The rise in non-competitive, or 'earmarked' funds disbursed outside agency initiated requests. (adapted from data reported in NSB 1991). Note: the 1991 NSF budget was \$1.954 billion, and the total research and development funds for educational institutions in 1988-9 was \$13.5 billion.

BIOGRAPHICAL INFORMATION

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DOUGLAS L. INMAN is Professor of Oceanography and founding Director of the Center for Coastal Studies, Scripps Institution of Oceanography, University of California, San Diego. During his more than thirty years of teaching at Scripps and research in many areas of the world, he has pioneered the field of beach and nearshore processes. He is a Guggenheim Fellow, and he has served as a UNESCO Lecturer in Marine Science in a number of countries. Dr. Inman is the author of over one hundred scientific publications, was technical director for the Orbit Award winning film, "The Beach: A River of Sand", and has received the American Society of Civil Engineers "International Coastal Engineering Award" (1988) and the "Ocean Science Educator Award" (1990) from the Office of Naval Research.

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JOY B. ZEDLER holds a Ph.D. in botany (plant ecology) from the University of Wisconsin. Since 1969 she has been at San Diego State University (SDSU) and is currently a professor of biology at SDSU and director of the Pacific Estuarine Research Laboratory. Her research interests include salt marsh ecology; structure and functioning of coastal wetlands; restoration and construction of wetland ecosystems; effects of rare, extreme events on estuarine ecosystems; dynamics of nutrients and algae in coastal wetlands; and the use of scientific information in the management of coastal habitats. She recently worked on a compilation of literature on the creation and restoration of wetlands for the U.S. Environmental Protection Agency. Dr. Zedler was appointed as a member of the Water Science and Technology Board July 1991.

